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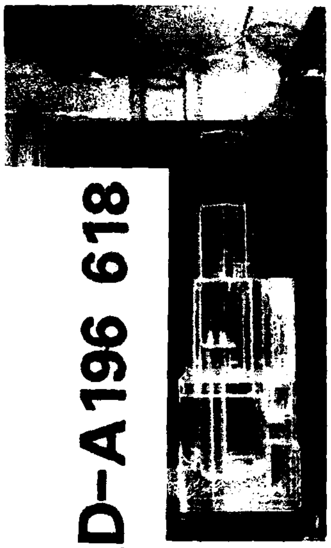

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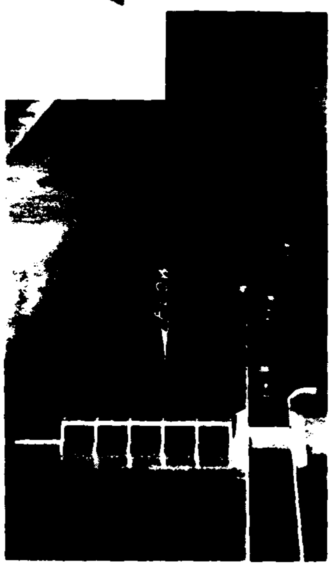

TECHNICAL REPORT HL-88-14

OLD RIVER CONTROL AUXILIARY STRUCTURE

Hydraulic Model Investigation

by

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Hydraulics Laboratory

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Model tests of the Old River Control Auxiliary Structure were conducted to investigate and develop a design that would provide satisfactory flow characteristics in the approach channel, at the abutments, over the spillway, in the stilling basin, and in the exit channel, and determine the adequacy of the riprap protection proposed for the approach and exit channels.

The approach channel provided satisfactory flow to the spillway for all anticipated flow conditions. A design for the approach training walls was developed.

Spillway discharge characteristics were determined for the following flow conditions: free uncontrolled flow, submerged uncontrolled flow, free controlled flow, and submerged controlled flow.

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Pressures measured on the crest indicated no negative pressure for any anticipated flow conditions. Hydraulic performance of the stilling basin was improved by elevating the stilling basin apron 15 ft and providing two rows of 15-ft-high baffles and a 12-ft-high end sill. Tests indicated that the downstream portion of the stilling basin training wall could be lowered for a length of 63 ft without impairing hydraulic performance. The magnitude and frequency of the hydraulic forces acting on the stilling basin sidewalls were computed.

The invert of the exit channel was elevated 5 ft for sediment transport and hydraulic purposes. The riprap design developed for the exit channel provided adequate protection for anticipated flow conditions, including 90,000 cfs passing through a single bay.

PREFACE

The model investigation reported herein was authorized by the Office, Chief of Engineers, US Army, on 16 January 1980, at the request of the US Army Engineer District, New Orleans (LMN).

The study was conducted during the period January 1980 to September 1981 by personnel of the Hydraulics Laboratory (HL) of the US Army Engineer Waterways Experiment Station (WES) under the direction of Messrs. H. B. Simmons, Chief, HL, and J. L. Grace, Jr., Chief, Hydraulic Structures Division, and under the general supervision of Mr. N. R. Oswalt, Chief, Spillways and Channels Branch. The engineers in immediate charge of the model were Messrs. B. P. Fletcher and P. Bhramayana, assisted by Messrs. B. Perkins and J. R. Rucker, Jr., all of the Spillways and Channels Branch. This report was prepared by Messrs. Fletcher and Bhramayana and edited by Mrs. Marsha C. Gay, Information Products Division, Information Technology Laboratory.

During the course of the investigation, Messrs. Rodney H. Resta, Henry G. Reed, Lawrence H. Cave, Jr., William P. Pinner, Loren Heiple, Victor M. Agostinelli, Roland J. Dubuisson, Frank J. Weaver, Robert L. Kaufman, H. Estes Walker, Lawrence F. Cook, Henry S. Martin, and Lawrence A. Rabalais, US Army Engineer Division, Lower Mississippi Valley; and Frederic M. Chatry, Robert T. Fairless, William W. Gwyn, Thomas H. Johnson, Jr., Thomas G. Hassenboehler, Jim L. Miles, Cecil W. Soileau, Tilden J. Dufrene, Jr., and Philip A. Becnel, Jr., LMN, visited WES to discuss the program of model tests and observe the model in operation.

COL Dwayne G. Lee, CE, is the Commander and Director of WES. Dr. Robert W. Whalin is the Technical Director.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
feet of water (39.2° F)	2,988.98	pascals
inches	25.4	millimetres
kips (force)	4.448222	kilonewtons
miles (US statute)	1.609344	kilometres
pounds (mass)	0.4535924	kilograms

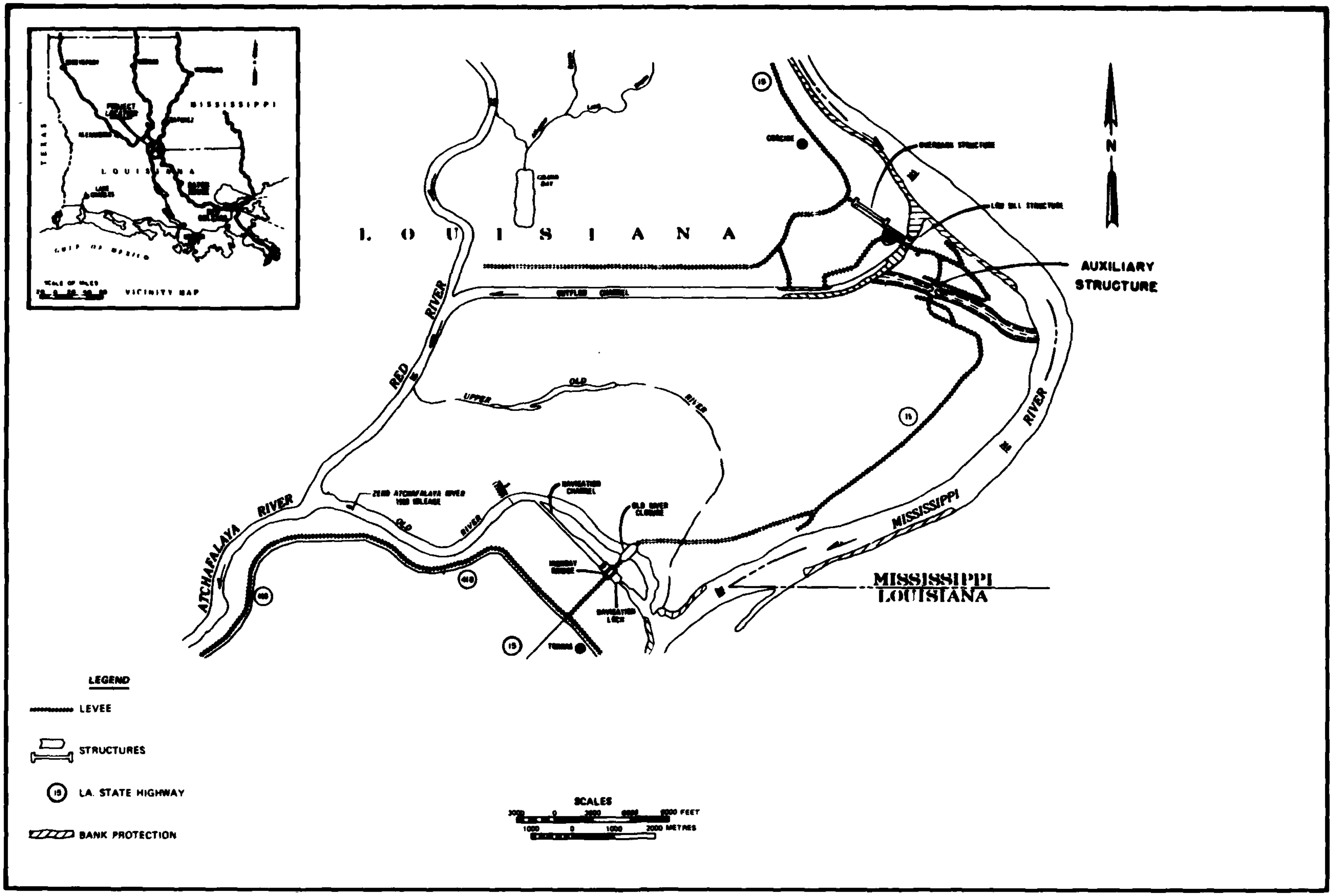

Figure 1. Site plan and vicinity map

OLD RIVER CONTROL AUXILIARY STRUCTURE

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. The Old River Control Auxiliary Structure (Figure 1) is located within the lower limits of the Red River backwater area on the west bank of the Mississippi River about 48 miles* northwest of Baton Rouge, Louisiana, and about 37 miles southwest of Natchez, Mississippi.

2. The approach channel to the structure (Plates 1 and 2) has a bottom width of 500 ft, an invert elevation of -10.0,** side slopes of 1V on 5H, and a length of approximately 2 miles from its junction with the Mississippi River. The approach training walls to the structure have a top el of 70.0.

3. The structure is pile founded, constructed of reinforced concrete, with a gross width of 442 ft between faces of abutment walls. The crest is surmounted by five 14-ft-wide piers that provide bays for six 62-ft-wide by 70-ft-high tainter gates (Plates 2 and 3). The gates are raised, lowered, and held in position by cables and drum hoists. The weir crest of the structure is at el -5.0 to provide sufficient discharge for navigation and water supply needs with minimum stages in the Atchafalaya Basin.

4. The stilling basin (Plates 2 and 3) has a length of 215 ft, width of 442 ft, and floor el of -20.0. Stilling basin training walls with a top el of 55.0 terminate at the end sill. Energy dissipation is provided by two rows of 15-ft-high baffles and a 12-ft-high end sill with a face slope of 1V on 1H. A concrete apron extends 105 ft downstream from the end sill. The apron has sidewalls with a top elevation that slopes from 7.5 ft at the end sill to -10 ft at the downstream end of the apron (Plates 2 and 3).

5. The outlet channel is lined with riprap and has a trapezoidal cross

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* A table of factors for converting non-SI units of measurement to SI (metric) units of measurement is found on page 3.

** All stages and elevations (el) referred to in this report are in feet referred to the National Geodetic Vertical Datum (NGVD).

section with an invert el of -10, a bottom width of 475 ft, and side slopes of 1V on 6H (Plates 1 and 2).

Purpose and Scope of Model Study

6. Although the spillway was well designed, model analysis was desired to determine whether the design met standards of economy, performance, and good engineering practice. The US Army Engineer District, New Orleans, was particularly concerned with verification of flow conditions in the approach channel, at the abutments, over the spillway, in the stilling basin, and in the exit channel, and of the adequacy of the riprap protection proposed for the approach and exit channels. The model study provided the data necessary to evaluate and develop a satisfactory means of regulating the structure to achieve the desired flow objectives without creating adverse hydraulic conditions. The following information was obtained:

a. Size and extent of riprap protection needed in the approach and exit channels.

b. Flow characteristics and stilling basin performance with gates fully open (uncontrolled flow).

c. Flow characteristics and stilling basin performance with partial closure of the gates (controlled flow).

d. Velocities in the approach, stilling basin, and exit channel.

e. Flow characteristics and stilling basin performance with one gate fully open and the other gates closed.

Definition of Flow Conditions

7. The various types of flow conditions discussed in this report are defined as follows:

a. Free uncontrolled flow. Gates fully open; upper pool unaffected by the tailwater.

b. Free controlled flow. Upper pool controlled by gate opening and unaffected by tailwater.

c. Submerged uncontrolled flow. Gates fully open; upper pool controlled by the submergence effect of the tailwater.

d. Submerged controlled flow. Upper pool controlled by gate opening and the submergence effect of the tailwater.

PART II: THE MODEL

Description

8. The Old River Control Auxiliary Structure model (Figures 2 and 3) was constructed to a linear scale ratio of 1:50. The model simulated a 1,750-ft-wide by 3,000-ft-long channel reach including a 1,000-ft length of the approach channel and the structure and a 2,000-ft length of the exit channel (Plate 1). The portions of the model representing the approach, exit, and overbank areas were molded of cement mortar to sheet metal templates and were given a brushed finish. The spillway crest, gates, crest piers, and inflow training walls were constructed of sheet metal. The nonoverflow sections of the dam, stilling basin apron, outflow training walls, baffle piers, and end sill were made of wood and chemically treated to prevent expansion.

9. Water used in the operation of the model was supplied by pumps, and

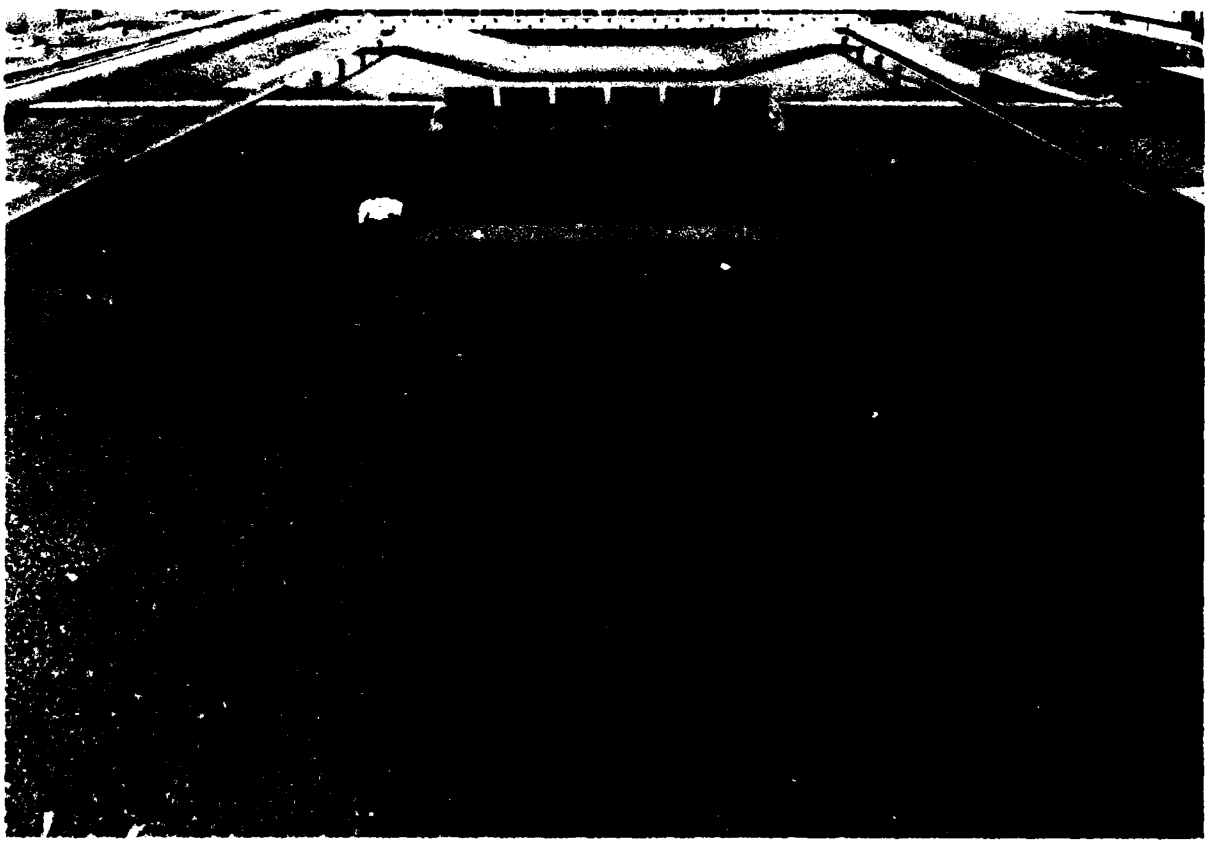
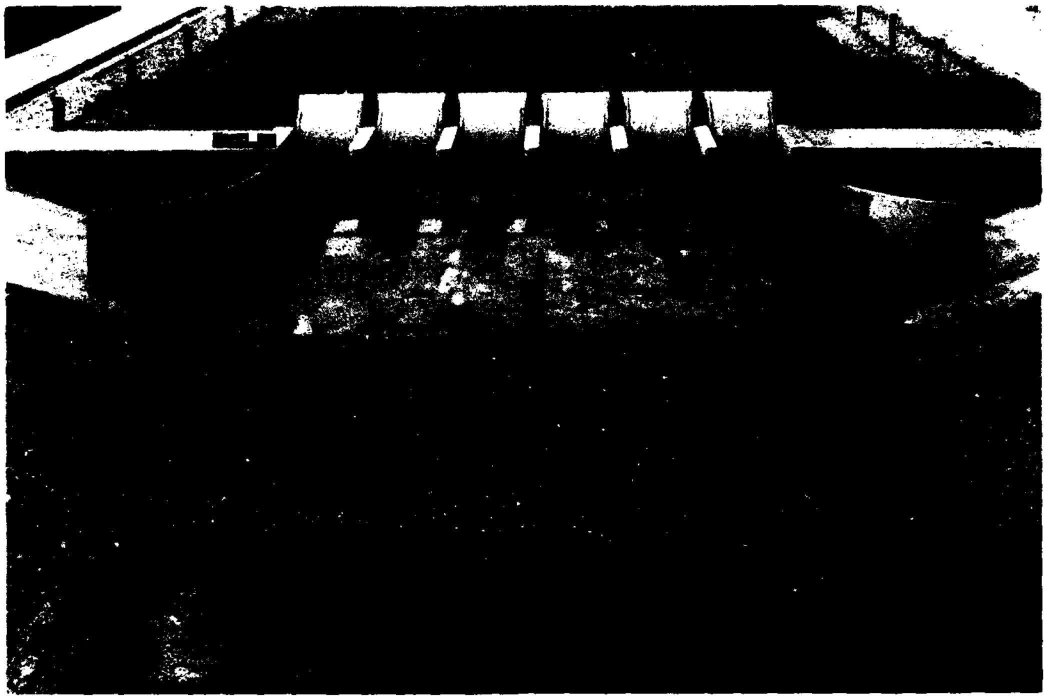
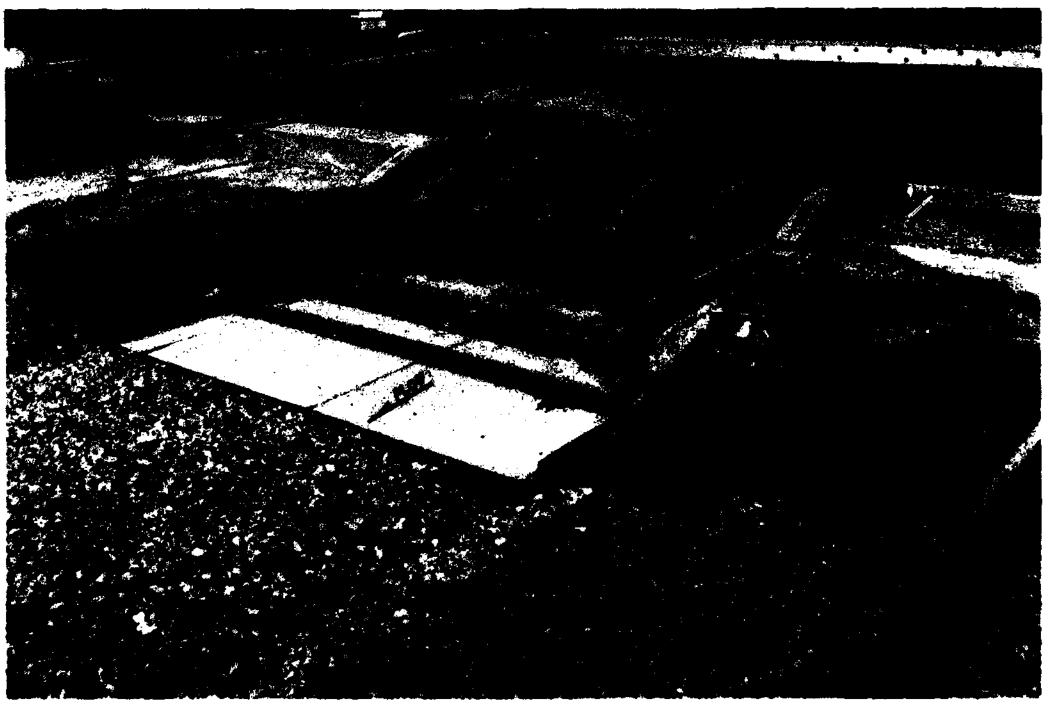


Figure 2. The 1:50-scale model looking upstream



a. Approach



b. Stilling basin

Figure 3. Approach and stilling basin of the 1:50-scale model

discharges were measured with venturi meters. Water entering the upstream end of the model was diffused by a manifold and a rock baffle to provide proper inflow distribution. Steel rails set to grade along both sides of the flume provided a reference plane for measuring devices. Water-surface elevations were measured by point gages. Velocities were measured with a pitot tube and by stopwatch timing of the movement of floatage and dye over measured distances. Current patterns were determined by observing the movement of dye injected into the water and confetti sprinkled on the water surface. Tailwater elevations were regulated by a tailgate located at the downstream end of the model.

Interpretation of Model Results

10. The accepted equations of hydraulic similitude, based on the Froude criteria, were used to express the mathematical relations between dimensions and hydraulic quantities of the model and prototype. General relations for transference of model data or length ratio L_r to prototype equivalents are presented in the following tabulation:

Dimension	Ratio	Scale Relation Model:Prototype
Length	L_r	1:50
Area	$A_r = L_r^2$	1:2,500
Volume	$V_r = L_r^3$	1:125,000
Velocity	$F_r = L^{1/2}$	1:7.071
Discharge	$Q_r = L_r^{5/2}$	1:17,677.67
Time	$T_r = L_r^{1/2}$	1:7.071
Weight	$W_r = L_r^3$	1:125,000

11. Model measurements of length, water-surface elevations, velocities, discharge, and riprap weight and size can be transferred quantitatively to prototype equivalents by means of the preceding scale relations.

PART III: TESTS AND RESULTS

12. For emergency operation, the spillway was required to satisfactorily pass discharges as great as 90,000 cfs through a single bay. The discharge requirements for a single bay dictated the hydraulic design of portions of the structure.

Approach Channel

13. The model reproduced 1,720 ft of the approach width for a distance of 2,000 ft upstream of the spillway as indicated by the dashed lines in Plate 1. Flows in the approach were well distributed and satisfactory for all anticipated discharges. Flow conditions and surface currents for four gate openings are illustrated in Photos 1-4. Current magnitudes and distributions measured 5 ft above the channel bottom in the approach to the structure for a single bay passing 90,000 cfs and for all bays passing a total of 374,000 cfs are shown in Plates 4 and 5, respectively.

Approach Training Walls

14. Tests conducted with various radii for the approach training walls indicated that the recommended approach training wall shown in Plate 2 provided satisfactory hydraulic performance for all anticipated flow conditions. There was no significant surging at the training walls or on the tainter gates during controlled releases. Plate 6 shows a plan view of the recommended design training walls and the buildup and drawdown of the water surface measured along the inside face of the left training wall for three flow conditions. Water-surface profiles for all flow conditions were similar along both the left and right upstream training walls.

Discharge Characteristics

Description of tests

15. Tests to determine the discharge characteristics of the spillway for free uncontrolled flow or free controlled flow were conducted by setting the lower pool elevation below the level of the spillway crest, setting a flow

rate, allowing the upper pool to stabilize, and measuring the upper pool elevation. The upper pool elevation was recorded for each discharge. Upper pool elevations were measured at a point 500 ft upstream from the axis of the spillway along the center line of the approach channel, and tailwater elevations were measured at a point 1,200 ft downstream from the axis of the spillway along the center line of the exit channel.

16. Discharge characteristics for submerged uncontrolled or controlled flows were determined by setting a discharge and varying the tailwater elevation in increments from an elevation that did not affect spillway capacity to higher elevations that caused a large degree of submergence. After the pool stabilized, the elevation of the upper pool was recorded for each corresponding tailwater elevation.

Presentation and analysis of data

17. The basic controlled flow calibration data obtained with various discharges from 10,000 to 550,000 cfs and gate openings G_o are presented in plots of approach energy elevation versus tailwater elevation (Plates 7-17). The basic uncontrolled flow calibration data are shown in Plate 18.

18. The calibration data were used to determine spillway discharge coefficients for the following flow conditions:

Free uncontrolled flow

$$Q = CLH^{3/2} \tag{1}$$

where C is a function of H as shown on Plate 19

Submerged uncontrolled flow

$$Q = C_s Lh\sqrt{2g\Delta H} \tag{2}$$

where C_s is a function of h/H as shown on Plate 20

Free controlled flow

$$Q = C_g LG_o\sqrt{2gH_g} \tag{3}$$

where C_g is a function of H_g and G_o as shown on Plate 21

Submerged controlled flow

$$Q = C_{g_s} Lh\sqrt{2g\Delta H} \qquad (4)$$

where C_{g_s} is a function of h/G_o as shown on Plate 22, and

Q = total discharge, cubic feet per second

C = discharge coefficient for free uncontrolled flow

L = net length of spillway crest, feet

H = total head on crest (including approach velocity head), feet

C_s = discharge coefficient for submerged uncontrolled flow

h = tailwater depth referred to crest, feet

g = acceleration due to gravity, feet per second per second

ΔH = difference between total energy head of the approach and depth of tailwater in reference to the crest $(H - h)$, feet

C_g = discharge coefficient for free controlled flow

G_o = gate opening, feet

H_g = total head on gate $(H - G_o/2)$, feet

C_{g_s} = discharge coefficient for submerged controlled flow

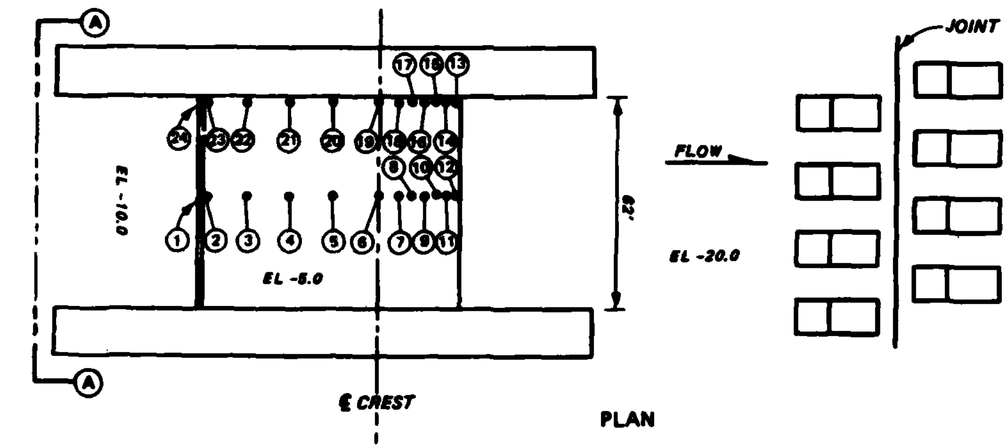
19. The data were analyzed to determine when the tailwater began to affect flow. The controlled flow regime for use in determining whether the free or submerged equation should be used is shown in Plate 23. The uncontrolled flow regime is shown in Plate 24.

20. Head-discharge relationships for free flow are presented in a different form in Plate 25.

21. An analysis of the data was made to develop generalized relations between swellhead, discharge, and tailwater elevation for free and submerged uncontrolled flow. Results of this analysis (Plate 26) indicate a transitional zone as shown between free and submerged uncontrolled flow.

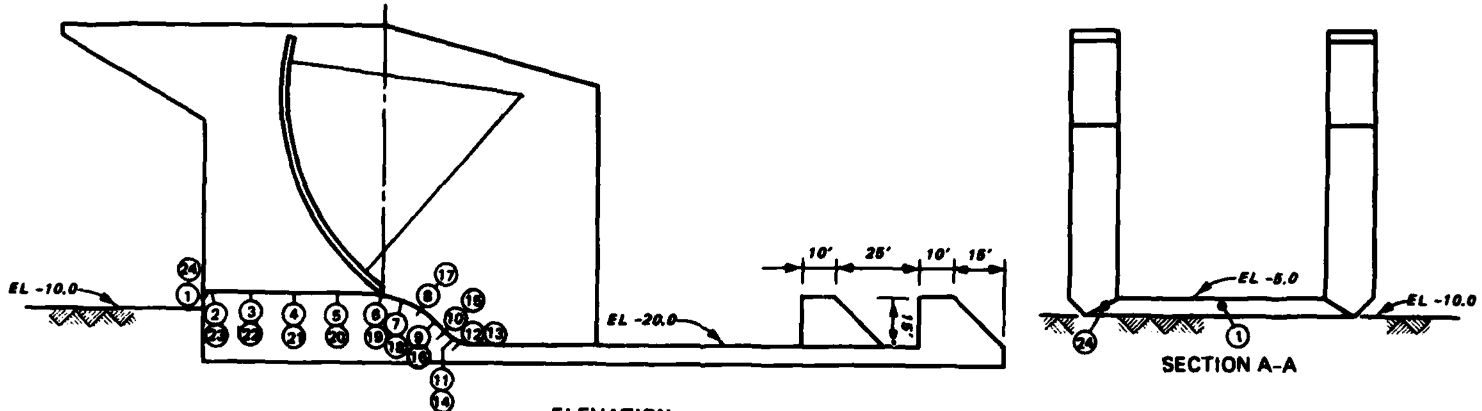
Crest and Apron Pressures

22. Tests were conducted to determine pressures on the spillway crest in the center and along the side of one gate bay with various flow conditions. The piezometer locations and elevations are shown in Figure 4. Test



PLAN

PIEZ NO.	DISTANCE FROM CREST ℄, FT	EL FT MSL
1, 24	-54	-7.0
2, 23	-50	-5.0
3, 22	-38	-5.0
4, 21	-26	-5.0
5, 20	-14	-5.0
6, 19	0	-5.0
7, 18	5	-5.6
8, 17	10	-7.2
9, 16	15	-10.0
10, 15	20	-13.9
11, 14	25	-18.9
12, 13	26	-20.0



SECTION A-A

ELEVATION

PIEZOMETER LOCATIONS

Figure 4. Piezometer locations and elevations for one gate bay, spillway crest

conditions are listed in Table 1, and pressures detected by the piezometers are tabulated in Table 2. The piezometer readings indicated that no negative pressures would occur in the center or along the sides of the gate bays. Pressures on the spillway apron were measured in a 1:50-scale section model. The section model was used, primarily, to determine the forces acting on the gate trunnions and stilling basin elements. Results of the section model study are presented in Fletcher and Grace.* Piezometer and electronic pressure cells were located in the apron, in a baffle, and in the sidewall, as shown in Figure 5. The stilling basin test conditions are listed in Table 3, and the magnitudes of the average pressures and instantaneous fluctuations of pressure for various discharges with the recommended stilling basin design are listed in Table 4.

Stilling Basin Performance

23. The original stilling basin design is shown in Figure 6 and Plate 27. Engineers of the New Orleans District indicated that it would be economically desirable to elevate the stilling basin apron as high as feasible without impairing the hydraulic performance of the structure. Subsequently the spillway model was used to develop the optimum stilling basin apron elevation; apron length; gate pier length; baffle block size and location; and the height, shape, and location of the end sill. Various stilling basin modifications were evaluated by monitoring the magnitude of current velocities and by visual observations of turbulence and waves. The New Orleans District furnished a list of hydraulic conditions (Table 5) to be investigated in the model. Initial tests with single gate bay operation indicated that passing 90,000 cfs through either end gate bay with a minimum anticipated tailwater el of 24.2 and a headwater el of 54.0 was the most critical of the hydraulic conditions listed in Table 5 and would probably dictate the design of the stilling basin.

Stilling basin apron

24. The optimum stilling basin apron elevation was determined by

* B. P. Fletcher and J. L. Grace, Jr. 1988 (Feb). "Hydrodynamic Forces on Tainter Gates and Stilling Basin; Old River Control Auxiliary Structure; Hydraulic Model Investigation," Technical Report HL-88-1, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

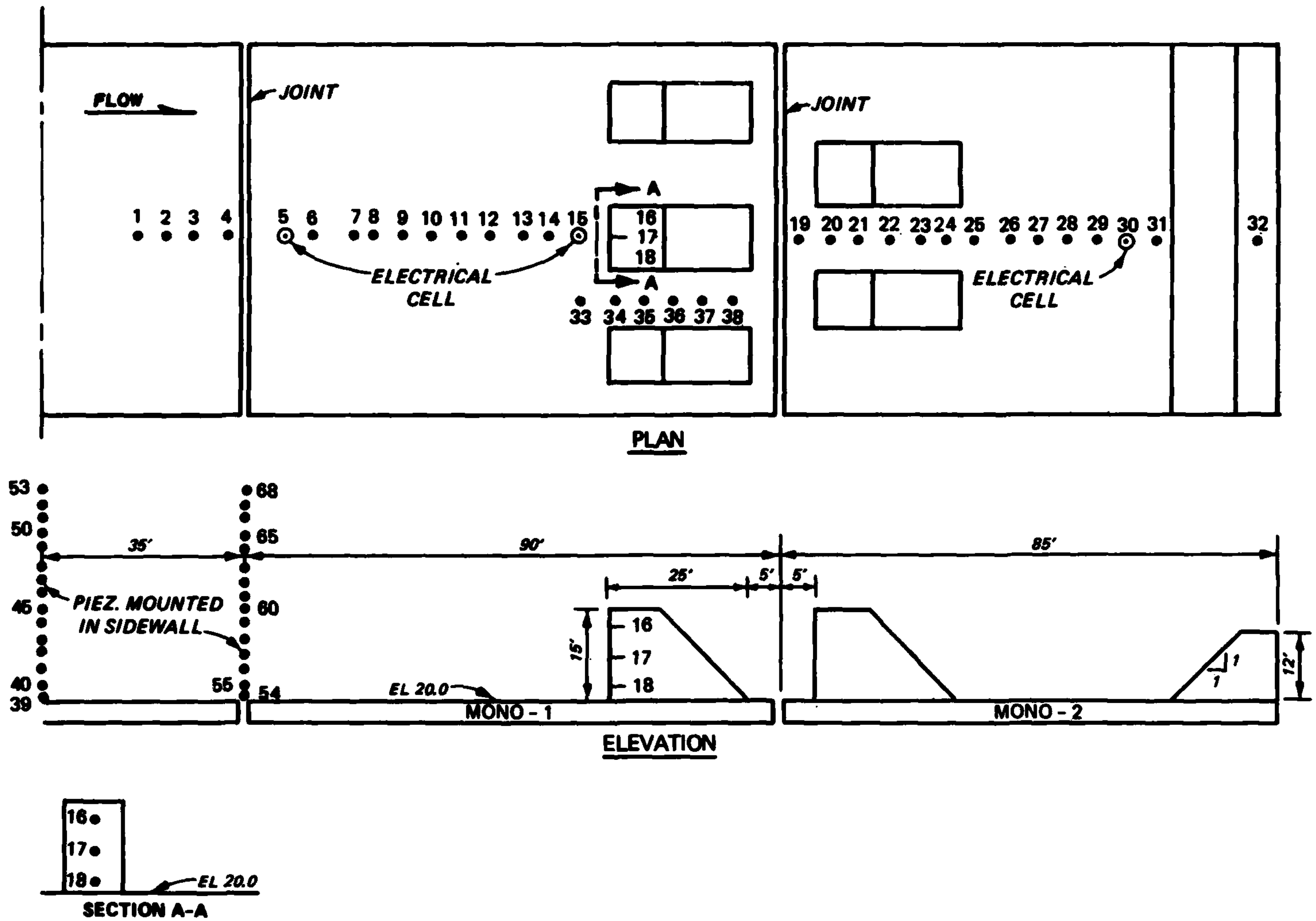


Figure 5. Location of piezometers and electronic pressure cells, apron, baffle, and sidewall

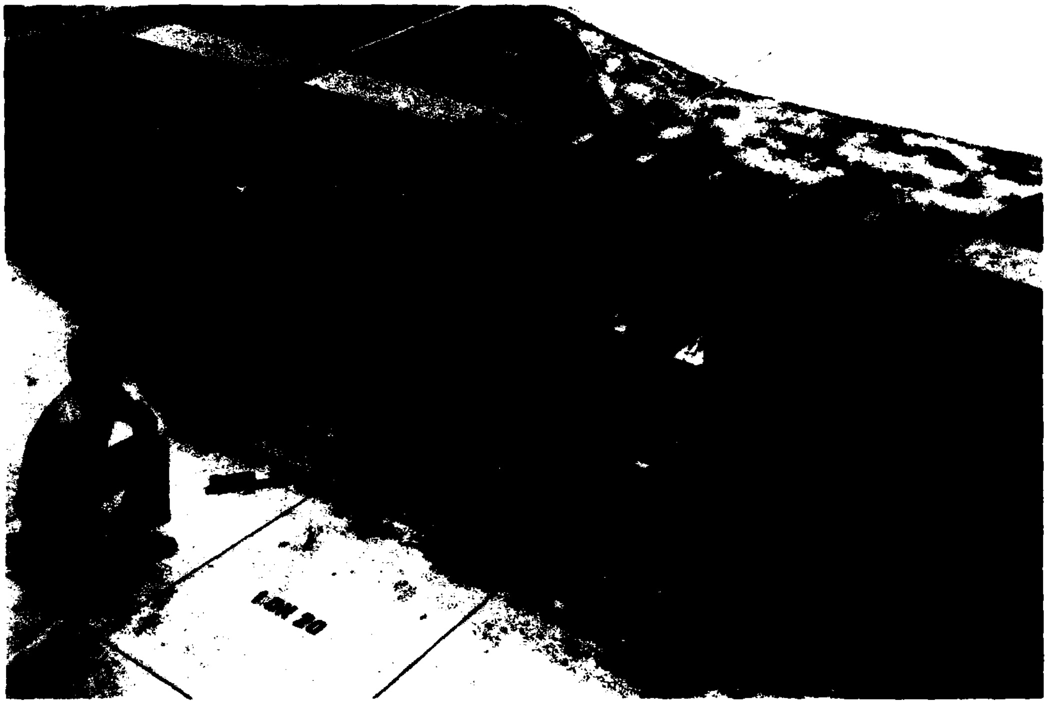


Figure 6. Original stilling basin design

evaluating hydraulic performance with various apron elevations. Tests and computations indicated that it would be hydraulically and economically feasible to elevate the apron. Flow conditions with the type 1 (original) design stilling basin apron are shown in Photos 5-7. Flow conditions with alternative designs, type 2 (apron el -25.0) and type 3 (apron el -15.0) design stilling basin aprons, are illustrated in Photos 8-9 and 10-11, respectively. The highest apron (el -15.0) did not provide satisfactory hydraulic performance with a discharge of 90,000 cfs passing through a fully opened single gate bay as excessive standing waves (Photo 10), turbulence, and unsatisfactory velocity distribution were observed. The type 4 (recommended) design stilling basin apron (el -20) was at the highest apron elevation that would maintain satisfactory hydraulic performance with fully open single gate operation. Velocities measured at the end of the apron with various apron elevations investigated are shown as isovels in Plates 28-39. A comparison of Plates 28-39 indicates that the best flow distribution is obtained with the apron located at el -20. Plate 40 indicates that the apron should not be higher than el -20 due to the excessive standing waves that occurred with a discharge of 90,000 cfs through a fully opened single gate. Additional tests

conducted with various baffle and end sill heights also indicated the apron should not be higher than el -20.

25. Computations to define the hydraulic characteristics to be expected in the stilling basin verified the results obtained in the model. For example, Plate 41 indicates that with a single gate passing 90,000 cfs and an apron elevation of -15.0 or higher, the Froude number in the stilling basin exceeds a value of 1.0 and supercritical flow exists. Plate 42 shows the ratio of the actual tailwater depth TW to the theoretical sequent depth required for hydraulic jump D_2 relative to the apron elevation for both a single gate open and all gates open. The plot indicates that single gate operation is the most adverse and that an apron elevation higher than -20.0 provides a ratio of tailwater depth to sequent depth less than 0.90 (the minimum desired to prevent spray action in the stilling basin). The plot of apron elevation versus discharge for flow conditions with all gates open (Plate 43) indicates that for a ratio of $TW/D_2 = 0.90$, the basin probably could be elevated to el -5.0. However, this elevation would not be satisfactory for single gate operation with a discharge of 90,000 cfs, which was the most adverse flow condition controlling hydraulic design of the stilling basin. The computations indicated that the type 4 stilling basin apron should provide satisfactory hydraulic performance for single and multiple gate operation.

Baffle blocks

26. Tests were conducted with the stilling basin apron at el -20 to determine the optimum size and location for two rows of baffle blocks. Blocks ranging in height from 10 to 20 ft were investigated. Again, the flow through a single gate bay passing 90,000 cfs was the most adverse hydraulic flow condition. Test results indicated that 20-ft-high (type 1) blocks generated adverse wave action. Type 2 baffle blocks (10 ft high) shown in Plate 44 did not induce sufficient energy dissipation. The type 3 (recommended) baffle blocks with a height of 15 ft and a width and spacing of 9 ft 10 in. (Plate 45) were favorable for both inducing energy dissipation and attenuating wave action in the stilling basin and exit channel. The type 3 baffle blocks were moved to various locations, and the hydraulic performance of the stilling basin was evaluated while passing 90,000 cfs through a single gate bay on the right side of the structure. The hydraulic performance was evaluated by measuring the magnitude of the velocity in the return flow on the left side of the exit channel 900 ft downstream from the stilling basin (Plate 46) and the

height of the standing waves in the stilling basin (Plate 47). The basic data are tabulated in Table 6.

End sill

27. Various end sill heights were investigated. Test results indicated that a 12-ft-high sloping end sill (type 2) positioned as shown in Plate 48 would provide the best hydraulic performance. End sill heights greater than 12 ft tended to generate standing waves in the exit channel, and lesser heights did not provide adequate flow distribution with single bay operation. Tests determined the optimum location of the 12-ft-high, sloping end sill to be a distance of 210 ft from the toe of the spillway (Plate 48). A plot of standing wave height versus distance from the end sill to the toe of the spillway is shown in Plate 49.

Stilling basin training walls

28. Tests to evaluate the stilling basin training wall design resulted in lowering the top elevation of the downstream 95-ft length of wall from el 55.0 to -8.0 (type 2 training walls, Plate 50). Additional tests indicated that the training walls should be revised as shown in Plate 51 (type 3 training walls) to provide a 10-ft parapet above the riprap behind the walls. This additional height reduced return flows into the stilling basin and reduced the turbulence over the riprap behind the training wall.

Additional modifications

29. Additional modifications tested as an effort to improve stilling basin performance included 25- and 50-ft-long pier extensions, a 1V on 5H sloping end sill, and a third row of baffles. Tests conducted with these modifications (Plate 52) indicated no significant improvement in hydraulic performance.

Recommended stilling basin

30. The recommended stilling basin design (Plates 3 and 51) was composed of the type 4 apron, type 3 baffle blocks, type 2 end sill, and type 3 stilling basin training walls. Test results indicate that this design stilling basin should provide adequate energy dissipation for all anticipated flow conditions including single gate bay or any combination of gate bays operating. Various flow conditions are shown in Photos 12-18. Water-surface profiles and basic data obtained for various flow conditions are shown in Plates 53 and 54.

31. Tests and data analyses for controlled and uncontrolled flows were

conducted to relate stilling basin performance with headwater and tailwater elevations, velocity, and gate opening (controlled flows only) as indicated in Plates 55-60. The curves in Plates 55-60 indicate that simulation of minimum tailwater elevations anticipated in the prototype or obtainable with channel control in the model would not sweep the hydraulic jump out of the stilling basin.

Exit Channel

32. The model reproduced 1,750 ft of the exit channel width for a distance of 2,000 ft downstream from the spillway as shown by the dashed lines in Plate 1. The type 1 original exit channel had 1V on 4H side slopes, and the channel invert was at el -15.0.

33. For the type 2 design, the channel side slopes were flattened to 1V on 6H (desired for geotechnical and economical purposes), and the channel invert was raised to el -10.0 (desired for hydraulic and sediment transport efficiency). Tests conducted with anticipated flow conditions (single and multiple gate operation) indicated no adverse hydraulic performance in the exit channel. Isovels obtained 105 ft downstream from the end sill and 305 ft downstream from the end sill are presented in Plates 61-64. The magnitude and distribution of currents measured 5 ft above the channel bottom in the exit channel for a single bay passing 90,000 cfs and for all bays passing a total of 374,000 cfs are shown in Plates 4 and 5, respectively.

34. The type 2 design exit channel was recommended for prototype construction because of geotechnical, hydraulic, sediment transport, and economic considerations.

Riprap Requirements

Original riprap protection

35. Tests were conducted to determine the most appropriate design of riprap for the recommended approach and exit channels. The riprap stability tests were conducted for the most severe hydraulic flow conditions resulting from discharge of 90,000 cfs through one end gate bay with a pool el of 53.0 and a tailwater el of 24.2. The type 1 design riprap plan simulated in the model is shown in Figure 7. The blanket thickness simulated was equivalent to

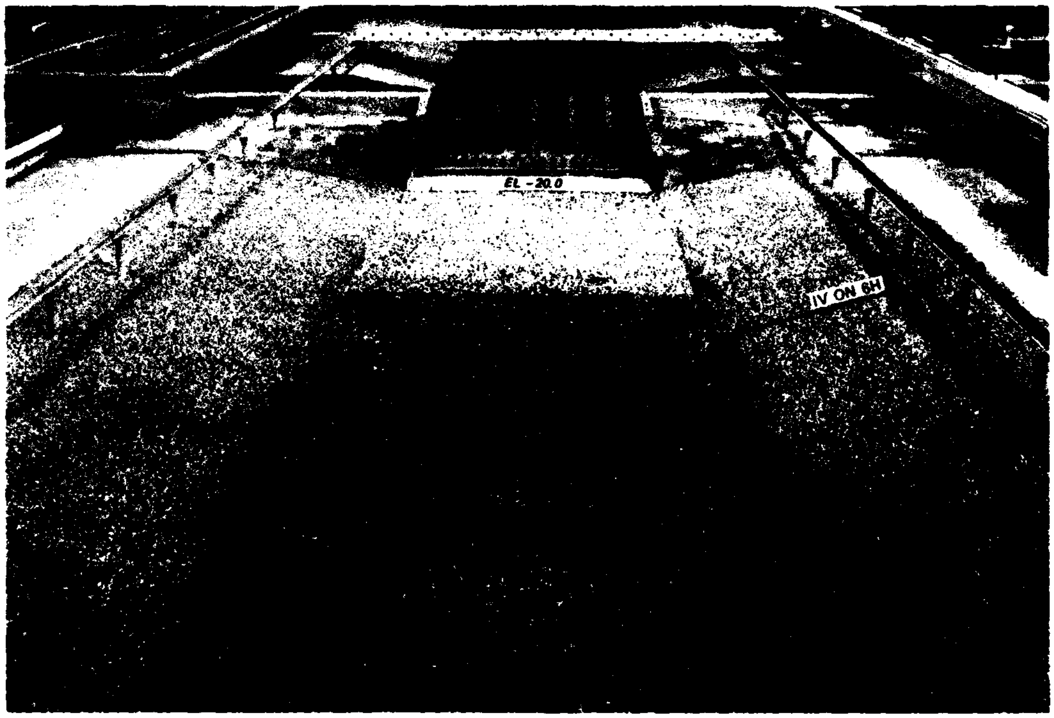


Figure 7. Type 1 riprap, type 2 exit channel

2.5 times the average size of the stone ($2.5d_{50}$). As indicated by the shaded areas shown in Plate 65, some of the riprap in the type 1 plan failed both upstream and downstream from the structure when it was subjected to 90,000 cfs through the end bay on the right side of the structure for a period of 15 hr (prototype).

36. The type 2 design riprap plan included a concrete apron between the downstream training walls. Riprap in the exit channel was stable for all anticipated flow conditions; however, failure was observed in the upstream approach as shown by the shaded areas in Plate 66.

Recommended riprap protection

37. The type 3 (recommended) design riprap plan for the approach and exit channels is shown in Plate 67. Plate 67 also presents details of all the riprap gradations as specified by the New Orleans District for the recommended design. When riprap in the approach and exit channels was subjected to a discharge of 90,000 cfs through a single end gate bay for a period of 150 hr (prototype), no stone failure was observed. The recommended riprap design was also subjected to various anticipated flow conditions including various

combinations of bays operating, the design discharge of 374,000 cfs (headwater el 52.0, tailwater el 38.6), and a discharge of 550,000 cfs (headwater el 66.2, tailwater el 61.0), the maximum discharge possible in the model without failure. Sufficient filter stone to prevent penetration of energy and the loss of soil from beneath the riprap by migration through the riprap blanket should not be overlooked. Two recommended sources of filter design criteria are EM 1110-2-1913* and ETL 1110-2-222.**

Forces acting on
stilling basin sidewalls

38. Computations (Plates 68 and 69) were made to estimate the magnitude and frequency of the dynamic forces to be exerted on the stilling basin sidewalls with a discharge of 90,000 cfs passing through a single end bay. This information was developed from limited test results obtained from an investigation conducted to determine dynamic forces acting on stilling basin sidewalls. Results obtained from the generalized research effort are based on experiments conducted without stilling basin elements (baffles and end sill). Therefore, the results presented in Plates 68 and 69 have been adjusted, based on engineering judgment, to include the effects of the baffles and end sill that are included in this stilling basin.

39. The forces and moment arms presented in Plates 68 and 69, respectively, are generated by the hydraulic jump within the stilling basin. Any additional forces due to soil and/or hydrostatic pressures on the back of the walls should be included in determining the total resultant forces. If the total resultant force is expected to be acting toward the basin, then the minimum instantaneous force curve should be used for design. If the resultant force is acting away from the basin, then the maximum instantaneous force curve should be used for design. Usually, due to the profile of a hydraulic jump, the minimum instantaneous force should be considered for design of the

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* Office, Chief of Engineers, US Army. 1978 (31 Mar). "Design and Construction of Levees," EM 1110-2-1913, US Government Printing Office, Washington, DC.

** Office, Chief of Engineers, US Army. 1978 (10 Jul). "Slope Protection Design for Embankments in Reservoirs," ETL 1110-2-222, US Government Printing Office, Washington, DC.

† Bobby P. Fletcher and Peter E. Saunders. "Dynamic Loading on Sidewall Monoliths of a Spillway Stilling Basin; Hydraulic Model Investigation" (in preparation), US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

upstream monoliths and the maximum instantaneous force should be used for the downstream monoliths.

PART IV: DISCUSSION OF TEST RESULTS

40. The model revealed that the approach channel provided satisfactory flow to the structure for all anticipated flow conditions including 90,000 cfs passing through a single bay. Approach training walls were developed that permitted flow to satisfactorily transition from the approach channel to the structure. There was no significant surging at the abutment or in the gate bays.

41. Tests were conducted to determine the spillway discharge coefficients for the following four possible flow conditions:

Free uncontrolled flow

$$Q = CLH^{3/2} \qquad \text{(1 bis)}$$

where C is a function of H as shown on Plate 19

Submerged uncontrolled flow

$$Q = C_s Lh\sqrt{2g\Delta H} \qquad \text{(2 bis)}$$

where C_s is a function of h/H as shown on Plate 20

Free controlled flow

$$Q = C_g LG_o\sqrt{2gH_g} \qquad \text{(3 bis)}$$

where C_g is a function of H_g and G_o as shown on Plate 21

Submerged controlled flow

$$Q = C_{g_s} Lh\sqrt{2g\Delta H} \qquad \text{(4 bis)}$$

where C_{g_s} is a function of h/G_o as shown on Plate 22.

42. Pressures measured on the crest and apron indicated that no negative pressures would occur for any anticipated flow condition.

43. Stilling basin design was dictated by the hydraulic condition of 90,000 cfs passing through a single bay. Hydraulic performance was improved

and costs reduced by elevating the stilling basin apron 15 ft from el -35.0 to -20.0 and providing two rows of 15-ft-high baffles and a 12-ft-high sloping end sill. The hydraulic jump will not be swept out of the stilling basin with this design during minimum tailwater elevation conditions.

44. Tests conducted to evaluate the stilling basin training walls indicated that the downstream portion of the walls could be lowered 63 ft without impairing hydraulic performance.

45. The invert of the exit channel was elevated from el -15.0 to -10.0 for hydraulic and sediment transport purposes. Satisfactory performance was observed for all anticipated flow conditions.

46. A design for riprap in the approach and exit channels was developed from the model. The recommended riprap provides adequate protection for various anticipated flow conditions, various combinations of bays operating, and a flow of 90,000 cfs passing through a single bay.

47. Computations were made to determine the magnitude and frequency of the hydraulic forces acting on the stilling basin sidewalls.

Table 1

Spillway Crest Pressures, Test Conditions

Test No.	Gate Opening, ft	Unit Discharge cfs/ft	Total Head on Crest, ft	Depth of Tailwater above Crest, ft
1	Full	1,450	53.7	24.3
2	36.0	1,005	52.0	38.6
3	25.0	715	52.5	33.7
4	11.0	269	69.0	54.0
5	6.0	177	68.6	45.6
6	15.0	285	70.2	61.8
7	16.0	392	52.6	38.3

Table 2

Spillway Crest Pressures, Recommended Design

Piezometer*		Crest Pressure, feet of water, for Test No.						
No.	El	1	2	3	4	5	6	7
1	-7.0	50.5	50.7	52.2	69.7	69.2	71.0	53.2
2	-5.0	34.2	41.3	47.0	69.0	68.8	70.4	51.5
3	-5.0	39.3	43.3	47.0	68.8	68.7	70.2	51.3
4	-5.0	35.4	39.5	42.0	67.1	68.1	68.5	58.5
5	-5.0	30.7	35.0	35.5	61.5	64.2	65.2	42.7
6	-5.0	15.1	23.8	20.5	49.3	42.6	59.0	30.8
7	-5.6	9.7	20.9	15.5	45.5	40.1	56.5	27.0
8	-7.2	11.1	23.7	15.0	44.6	39.1	56.2	26.5
9	-10.0	20.9	32.7	24.0	46.0	40.4	57.2	28.9
10	-13.9	27.3	33.5	31.5	50.4	43.1	61.0	35.0
11	-18.9	27.0	32.5	30.5	55.8	45.8	64.2	40.0
12	-20.0	27.1	33.0	30.0	58.9	53.5	65.2	41.8
13	-20.0	25.7	32.8	29.5	55.8	50.1	63.1	39.0
14	-18.9	24.1	31.3	27.5	52.9	47.8	61.5	35.5
15	-13.9	23.1	31.2	26.5	52.2	42.8	61.0	35.3
16	-10.0	21.5	31.5	25.5	50.8	40.8	60.9	34.0
17	-7.2	16.5	29.9	22.5	41.7	38.5	59.2	30.5
18**	-5.6	21.7	26.8	46.0	53.9	47.5	62.2	39.0
19	-5.0	21.3	30.3	25.0	51.2	45.3	60.2	34.0
20	-5.0	30.7	34.9	35.0	60.9	63.5	65.0	42.2
21	-5.0	36.1	40.2	42.5	67.2	68.0	68.8	49.0
22	-5.0	36.2	41.4	34.5	68.6	68.6	69.8	51.0
23**	-5.0	35.0	38.2	34.5	54.9	46.5	62.4	38.5
24	-7.0	45.1	52.2	53.0	69.7	69.5	71.2	53.5

* Piezometer locations are shown in Figure 4.

** Piezometer malfunction.

Table 3

Stilling Basin Pressures, Test Conditions

Test No.	Gate Opening, ft	Unit Discharge cfs/ft	Total Head on Crest, ft	Depth of Tailwater above Crest, ft
27	Full	1,370	52.0	24.3
28	11.0	280	69.0	53.0
29	35.0	950	55.0	39.0
30	6.4	177	69.1	45.1
31	15.0	400	52.0	35.0

Table 4

Stilling Basin Pressures, Recommended Design

Piezometer*		Crest Pressure, feet of water, for Test No.				
No.	El	27	28	29	30	31
1	-20.0	35.5	56.0	43.0	45.0	37.0
2		34.0	55.0	43.0	45.0	35.0
3		31.5	54.0	42.0	44.0	34.0
4		29.5	53.0	41.0	44.0	34.0
5		3.5	3.0	3.0	3.0	3.0
6		28.0	53.0	40.0	45.0	34.0
7		28.6	53.0	41.0	45.0	34.0
8		29.5	53.0	41.0	45.0	34.0
9		†	†	†	†	†
10		†	†	†	†	†
11		31.0	53.0	41.0	45.0	35.0
12		†	†	†	†	†
13		36.0	55.0	45.0	45.0	36.0
14		39.0	56.0	47.0	47.0	38.0
15**		6.5	4.0	4.0	3.0	5.0
16	-7.5	49.0	60.0	54.0	48.0	40.0
17	-12.5	51.0	64.0	55.0	52.0	45.0
18	-17.5	49.5	63.0	53.0	53.0	45.0
19	-20.0	†	†	†	†	†
20		22.0	53.0	39.0	45.0	35.0
21		23.5	53.0	40.0	45.0	35.0
22		25.5	53.0	40.0	45.0	35.0
23		26.0	53.0	40.0	45.0	36.0
24		26.5	54.0	41.0	46.0	36.0
25		27.0	54.0	41.0	46.0	36.0
26		27.0	53.0	41.0	45.0	36.0
27		28.0	53.0	41.0	45.0	36.0
28		28.0	53.0	40.0	46.0	37.0
29		29.0	54.0	40.0	46.0	37.0
30**		3.5	1.5	1.5	1.5	1.5
31		29.0	54.0	41.0	46.0	37.0
32	-8.0	19.0	54.0	38.0	46.0	36.0
33	-20.0	37.5	53.0	45.0	46.0	39.0
34		26.0	51.0	39.0	44.0	33.0
35		16.5	47.0	33.0	41.0	30.0
36		19.0	50.0	36.0	43.0	32.0
37		23.0	51.0	38.0	44.0	33.0
38		26.0	53.0	39.0	45.0	34.0
39	-19.0	26.0	53.0	35.0	48.0	37.0
40	-15.0	25.0	52.0	36.0	46.0	33.0
41	-10.0	25.0	54.0	37.0	46.0	33.0
42	-5.0	25.0	54.0	38.0	45.0	33.0
43	0	24.0	53.0	38.0	45.0	33.0

(Continued)

* Piezometer locations are shown in Figure 5.

** Electronic pressure cells--amplitude of maximum pressure fluctuations in feet.

† Piezometer malfunction.

Table 4 (Concluded)

Piezometer No.	Piezometer El	Crest Pressure, feet of water, for Test No. 27	28	29	30	31
44	5.0	23.0	53.0	38.0	45.0	33.0
45	10.0	↓	53.0	37.0	44.0	34.0
46	15.0		53.0	38.0	↓	↓
47	20.0		53.0	38.0		
48	25.0		53.0	38.0		
50	35.0		52.0	37.0		
51	40.0		53.0	37.0		
52	45.0		53.0	37.0		
53	50.0		53.0	37.0		
54	-19.0	29.5	54.0	42.0	45.0	35.0
55	-15.0	27.0	53.0	40.0	45.0	34.0
56	-10.0	25.0	53.0	38.0	45.0	↓
57	-5.0	24.0	53.0	39.0	45.0	
58	0	24.0	52.0	38.0	45.0	
59	5.0	23.0	52.0	39.0	44.0	
60	10.0	↓	53.0	38.0	↓	
61	15.0		↓	↓		
62	20.0					
63	25.0					
64	30.0					
65	35.0					
66	40.0					
67	45.0					
68	50.0					

Table 5

Hydraulic Design Conditions*

Model Testing Program

Flow Conditions	Headwater El	Tailwater El	Discharge cfs
Normal operation			
	10.0	7.8	17,000
	30.0	23.0	63,000
	52.0	38.3	146,000
	69.1	53.3	146,000
	10.0	6.5	11,000
	30.0	19.9	45,000
	52.0	32.8	105,000
	69.1	45.9	66,000
	69.1	61.8	106,000
Extreme conditions			
One gate full open, low sill and overbank closed	52.0	24.2	90,000
One gate full open, low sill partially open	52.0	30.0	90,000
Two gates closed	44.0	27.0	70,000
Low sill and overbank closed	52.0	38.6	374,000
	52.0	33.3	266,000

* Furnished by New Orleans District.

Table 6

Hydraulic Performance

Type 4 Stilling Basin Apron (El -20)

Type 3 Baffle Blocks (Height 15 ft)

Position	Distance from Toe of Spillway, ft	Wave Height, ft*	Return Velocity, fps**	Maximum Velocity, fps†
1	70	9.5	17.9	29.3
2	80	8.0	17.0	37.6
3	90	6.5	17.0	35.4
4††	95	5.5	17.0	35.0
5	100	6.5	17.0	35.8
6	110	9.0	18.8	35.0
7	130	11.0	19.7	35.4

Note: Each baffle block width and its spacing are 9 ft 10 in.

* Average height of standing wave in the stilling basin.

** Measured on the left bank 900 ft downstream from structure.

† Maximum velocity in stilling basin; discharge 90,000 cfs with one gate fully open; pool el 54.0; tailwater el 24.2.

†† Recommended position shown in Plate 51.

Photo 1. Approach flow, discharge 266,000 cfs, pool el 52.0, tailwater el 33.3, gate opening 25 ft, 15-sec exposure time (prototype)

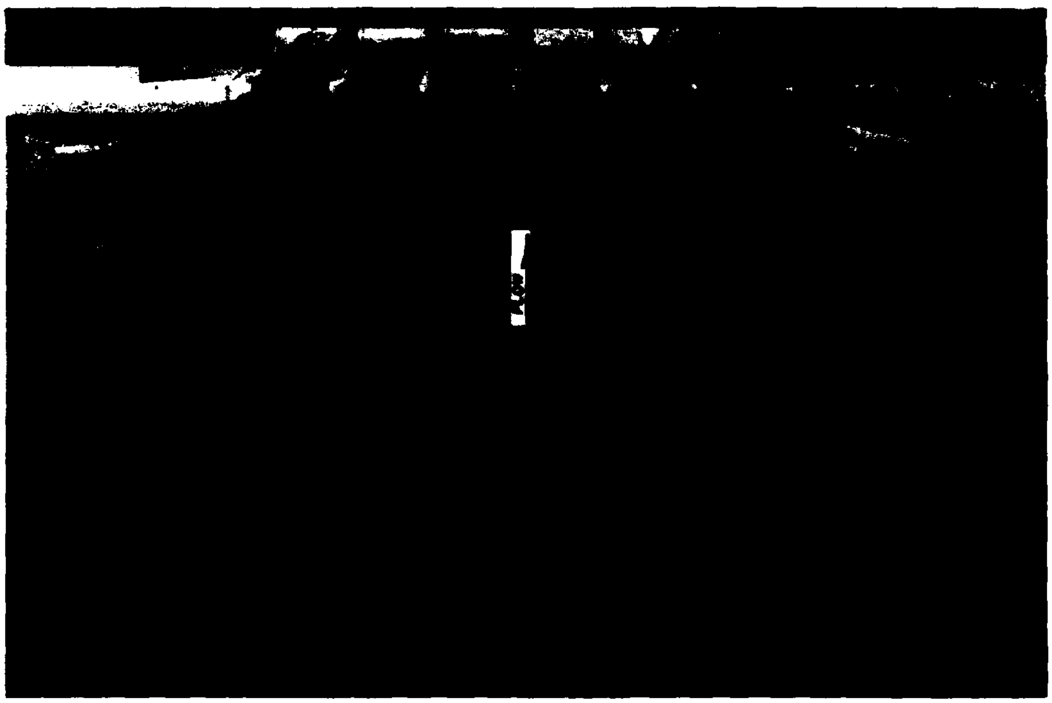


Photo 2. Approach flow, discharge 374,000 cfs, pool el 52.0, tailwater el 38.6, gate opening 36.5 ft, 15-sec exposure time (prototype)

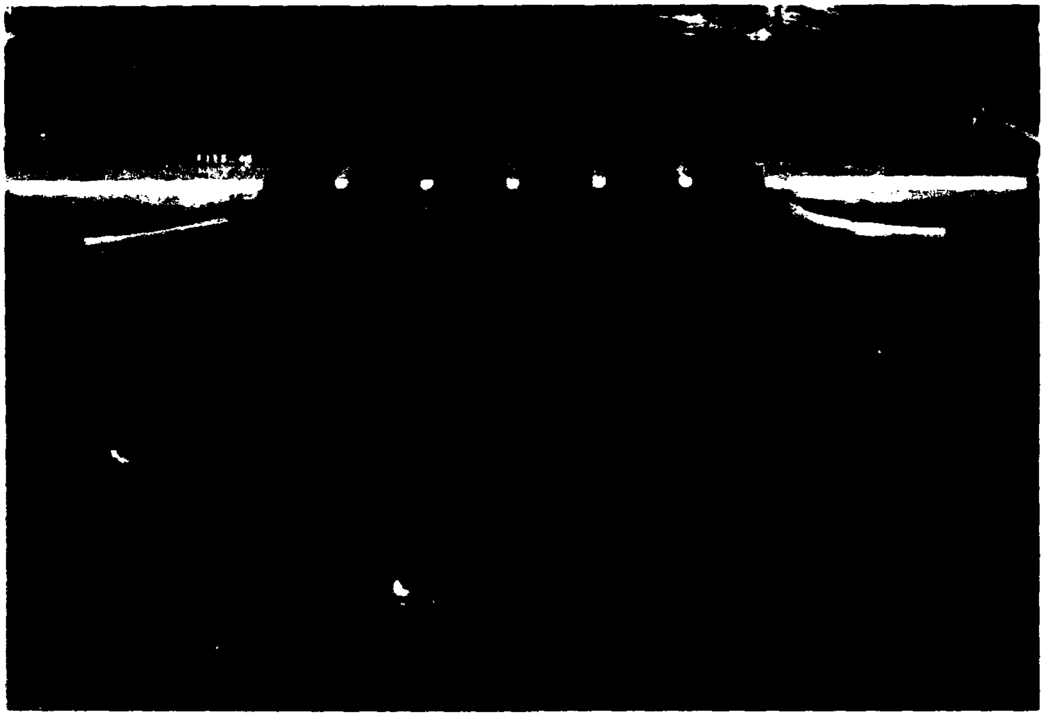


Photo 3. Approach flow, discharge 550,000 cfs, pool el 66.4, tailwater el 61.4, gates fully open

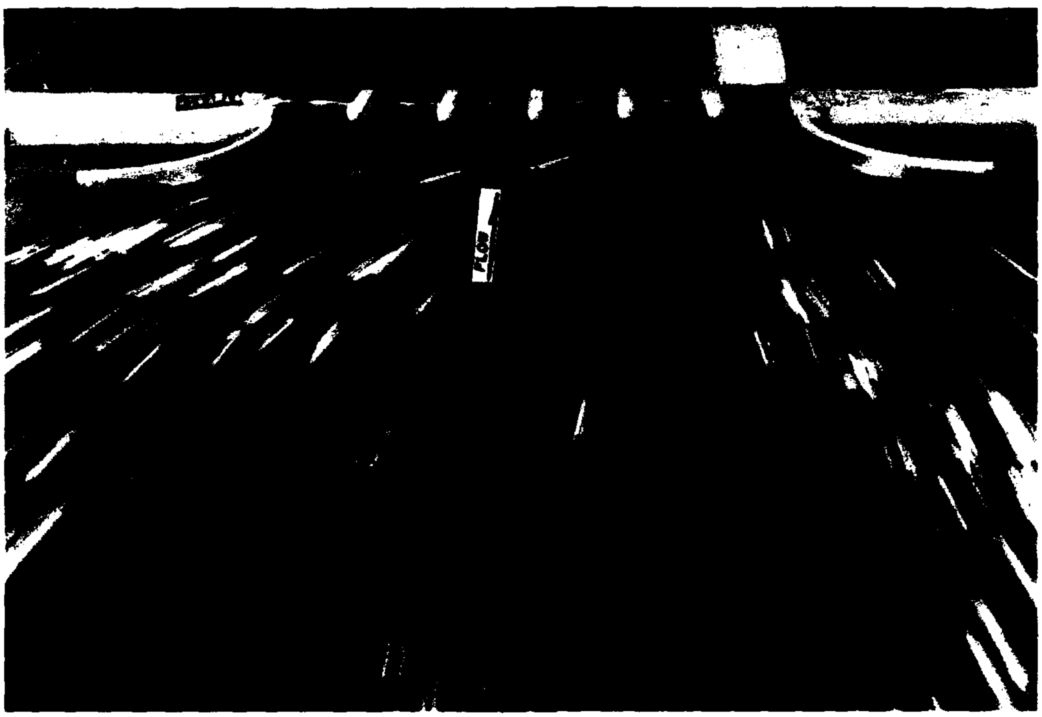
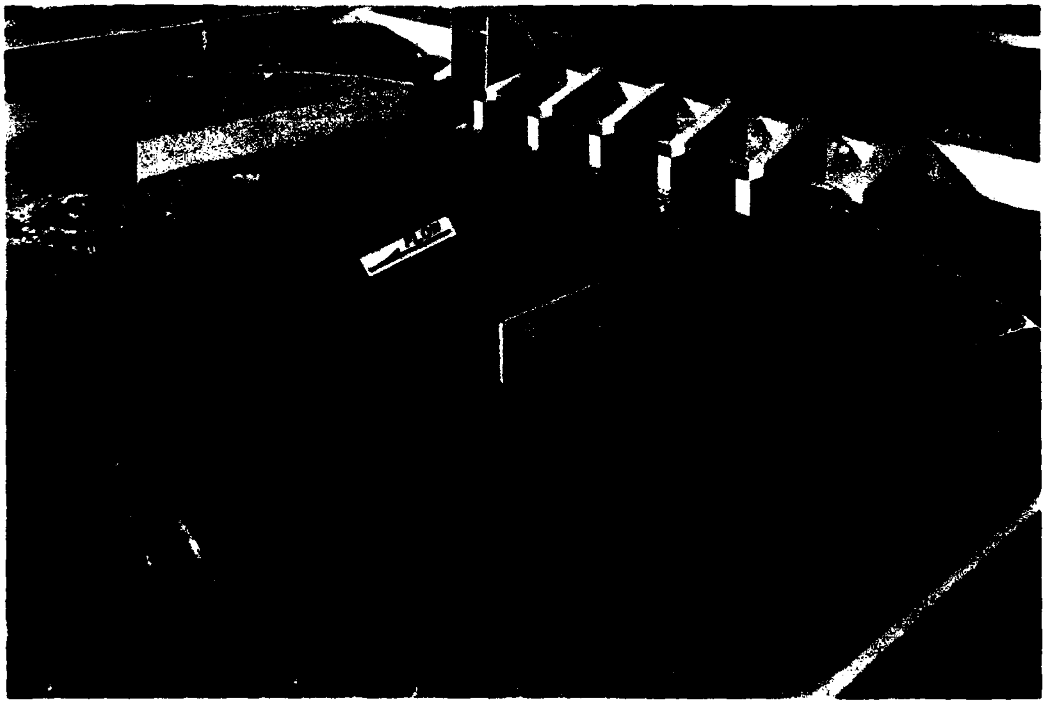


Photo 4. Approach flow, discharge 90,000 cfs, pool el 55.0, tailwater el 24.2, one gate fully open, 15-sec exposure time (prototype)



a. Side view

b. Downstream view, 15-sec exposure time
(prototype)

Photo 5. Type 1 (original) design stilling basin apron, discharge 90,000 cfs, pool el 54.0, tailwater el 24.2, one gate fully open

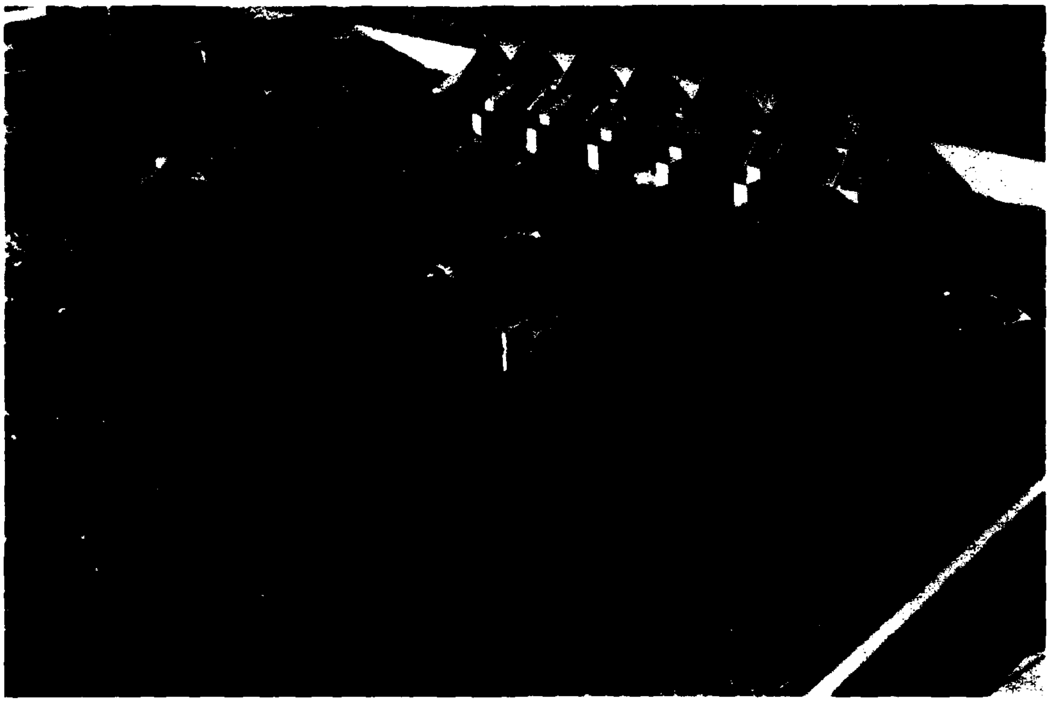


Photo 6. Type 1 (original) design stilling basin apron, discharge 374,000 cfs, pool el 52.6, tailwater el 38.6, gate opening 32.5 ft

Photo 7. Type 1 (original) design stilling basin apron, discharge 550,000 cfs, pool el 66.2, tailwater el 61.4, all gates fully open

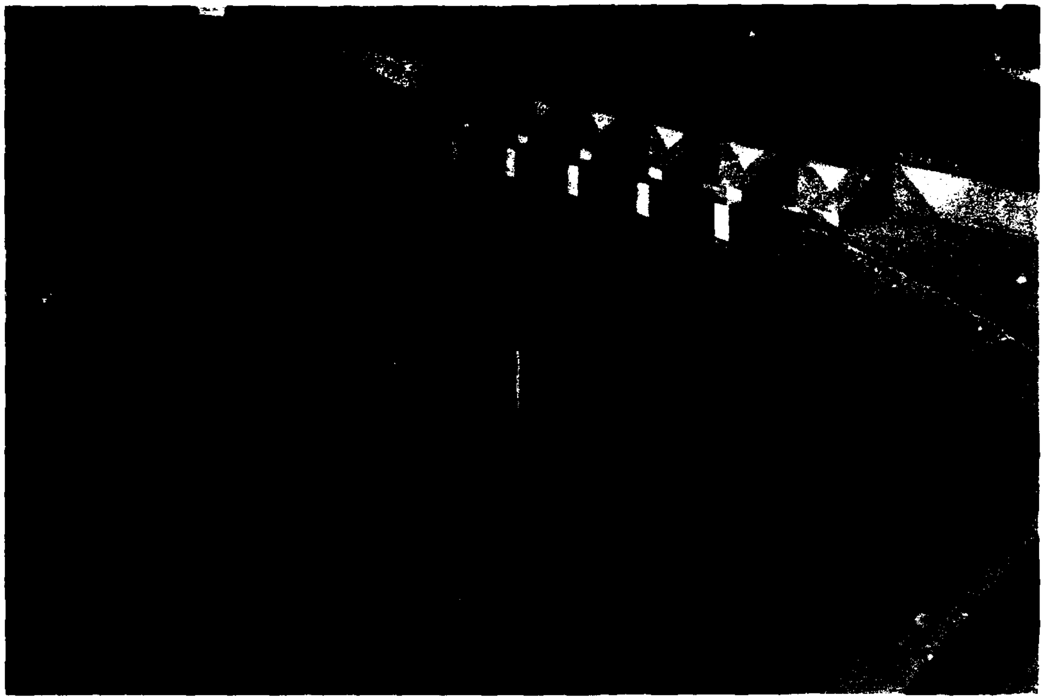


Photo 8. Type 2 design stilling basin apron, discharge 90,000 cfs, pool el 55.6, tailwater el 24.2, one gate fully open

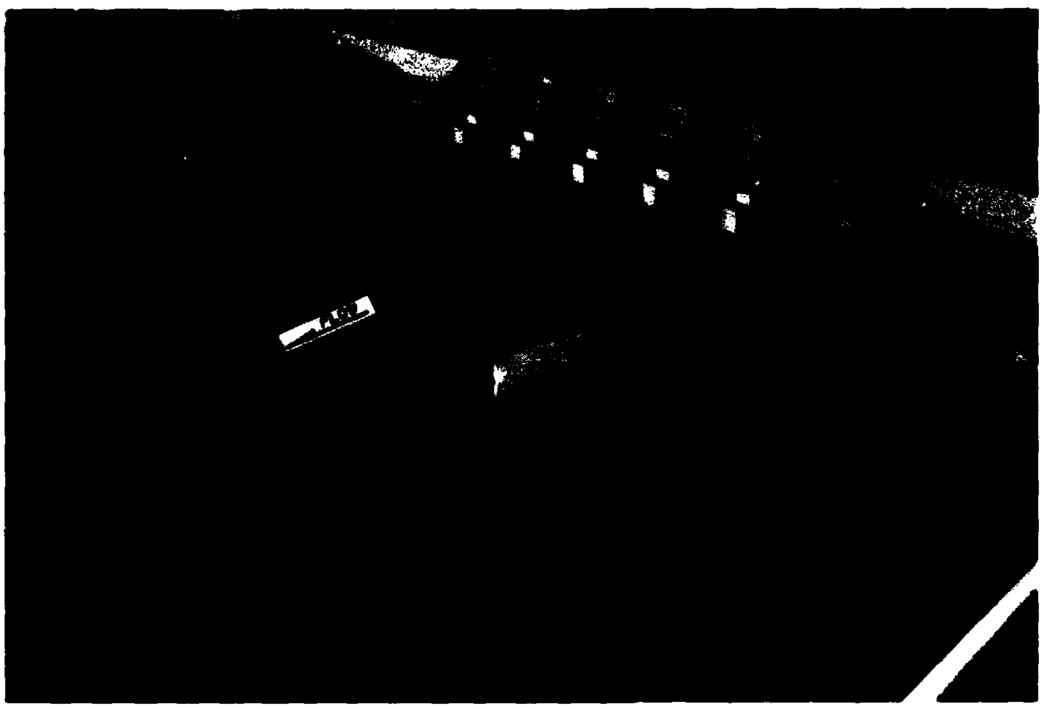


Photo 9. Type 2 design stilling basin apron, discharge 374,000 cfs, pool el 54.4, tailwater el 38.6, gate opening 35.0 ft

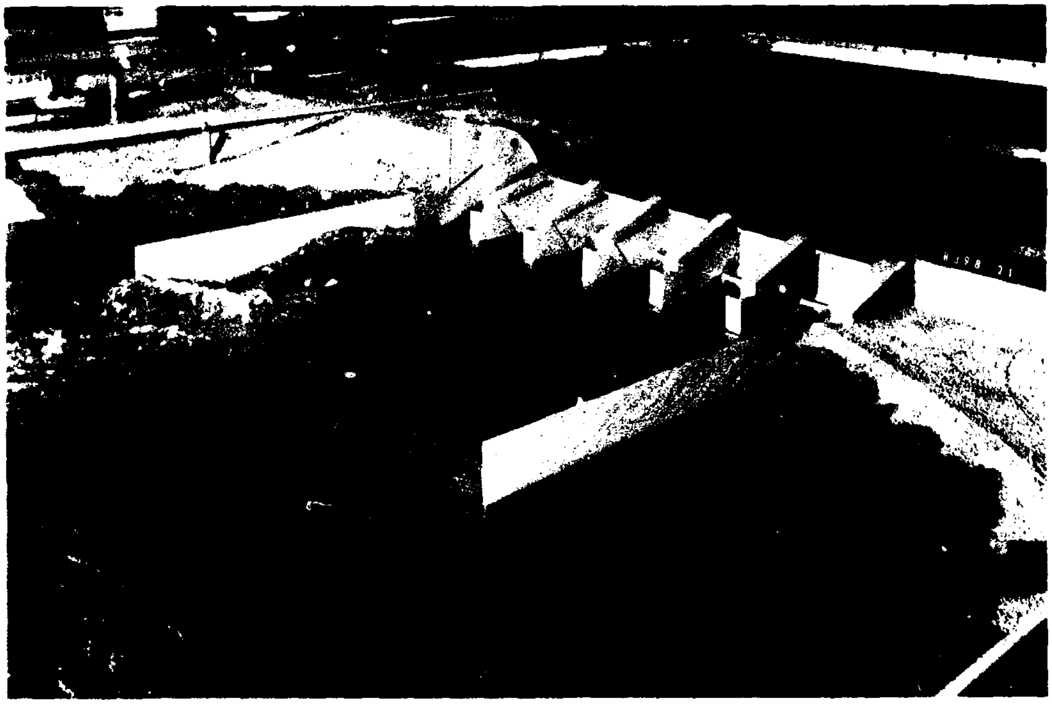


Photo 10. Type 3 design stilling basin apron, discharge 90,000 cfs, pool el 52.1, tailwater el 24.2, one gate fully open

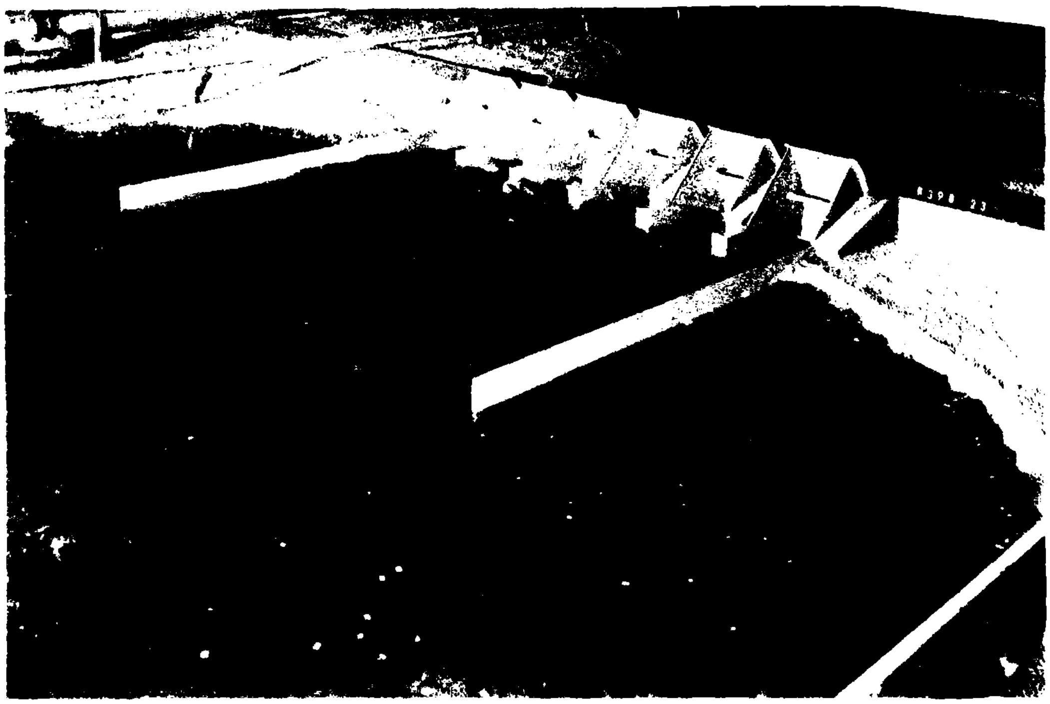


Photo 11. Type 3 design stilling basin apron, discharge 374,000 cfs, pool el 54.0, tailwater el 38.6, gate opening 35.0 ft

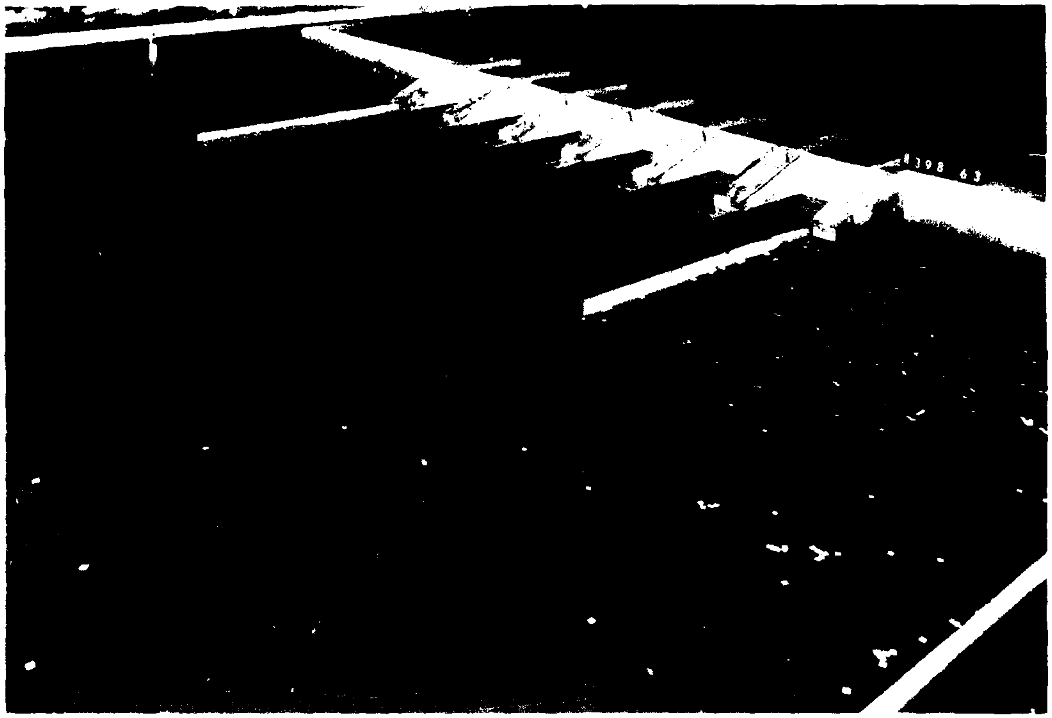


Photo 12. Recommended stilling basin design, discharge 66,000 cfs pool el 69.1, tailwater el 45.9, gate opening 6.0 ft

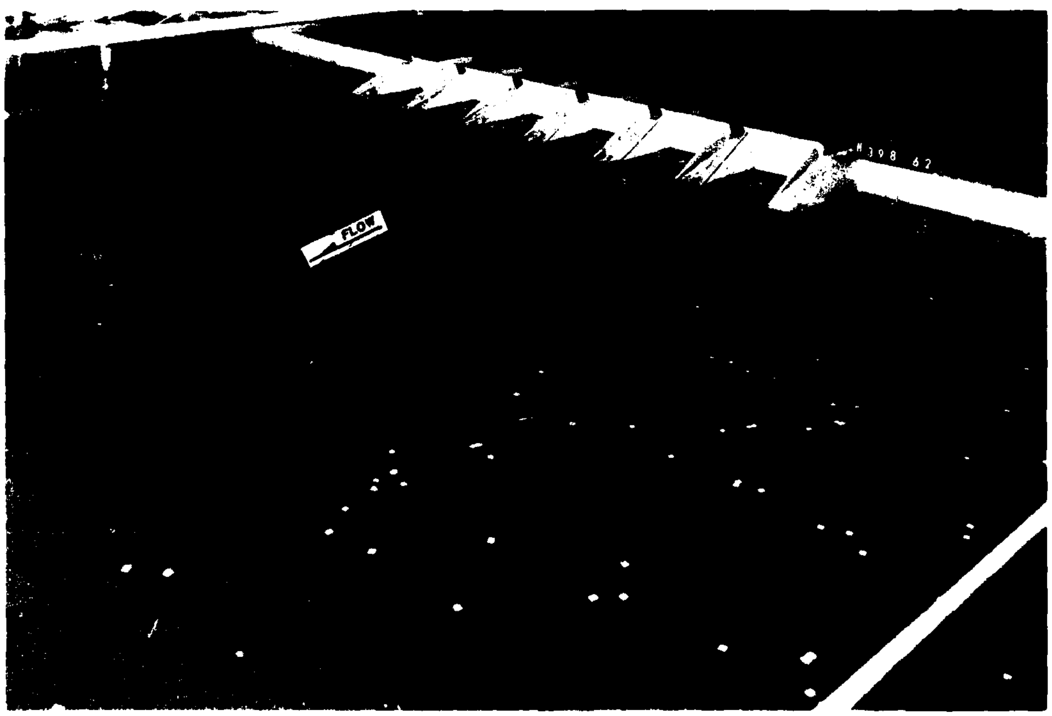
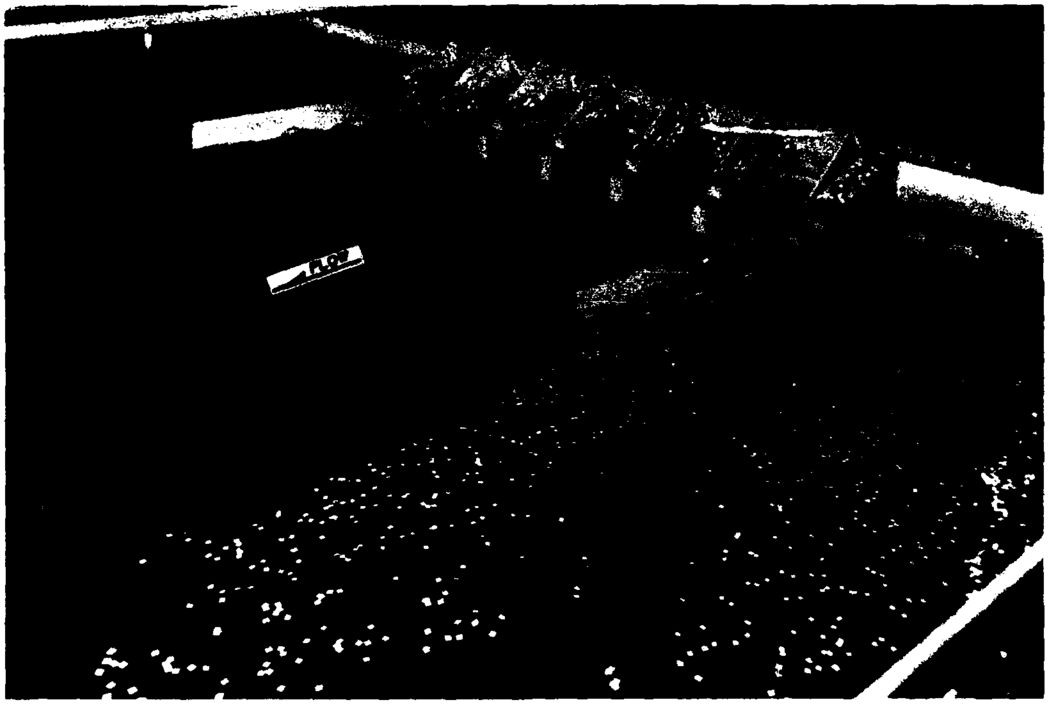
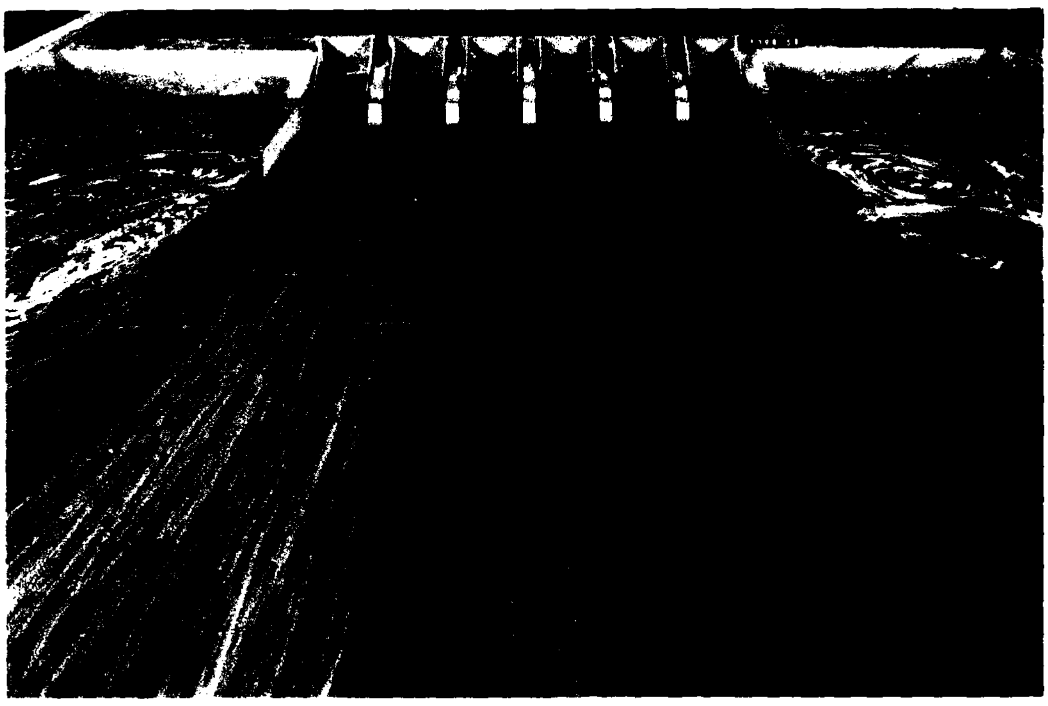


Photo 13. Recommended stilling basin design, discharge 106,000 cfs, pool el 69.1, tailwater el 61.8, gate opening 15.0 ft



a. Side view



b. Downstream view, 15-sec exposure time
(prototype)

Photo 14. Recommended stilling basin design, discharge 266,000 cfs,
pool el 52.0, tailwater el 33.3, gate opening 25.0 ft

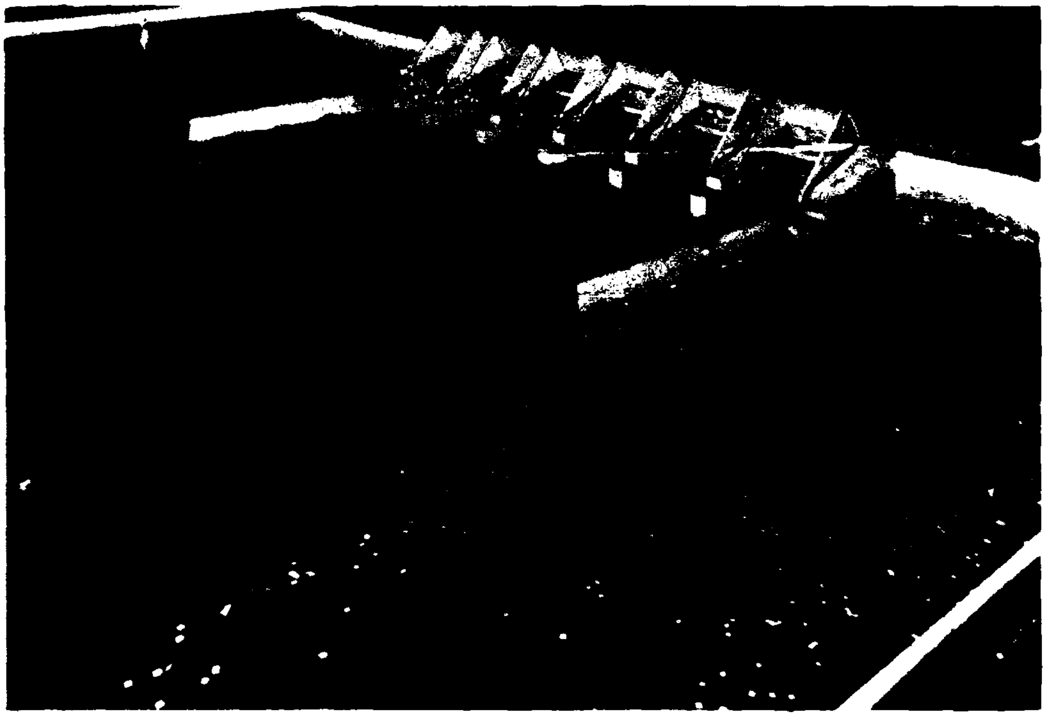


Photo 15. Recommended stilling basin design, discharge 374,000 cfs, pool el 52.0, tailwater el 38.6, gate opening 36.0 ft

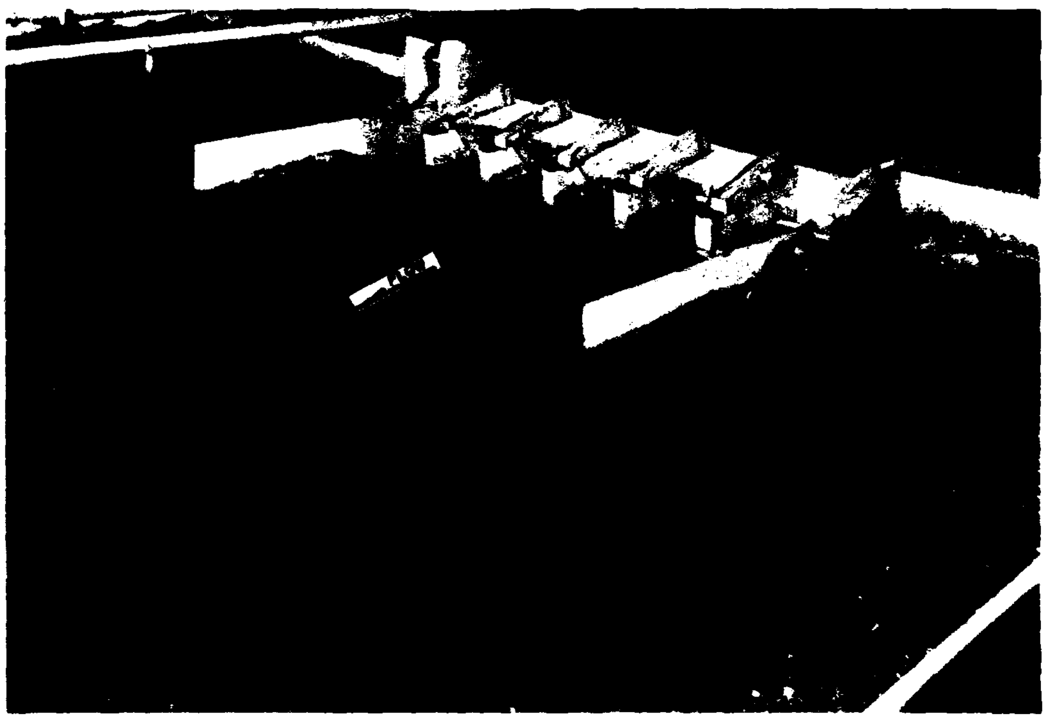


Photo 16. Recommended stilling basin design, discharge 90,000 cfs, pool el 55.0, tailwater el 24.2, one gate fully open

Photo 17. Recommended stilling basin design, discharge 30,000 cfs, pool el 24.7, tailwater el 6.5, one gate fully open

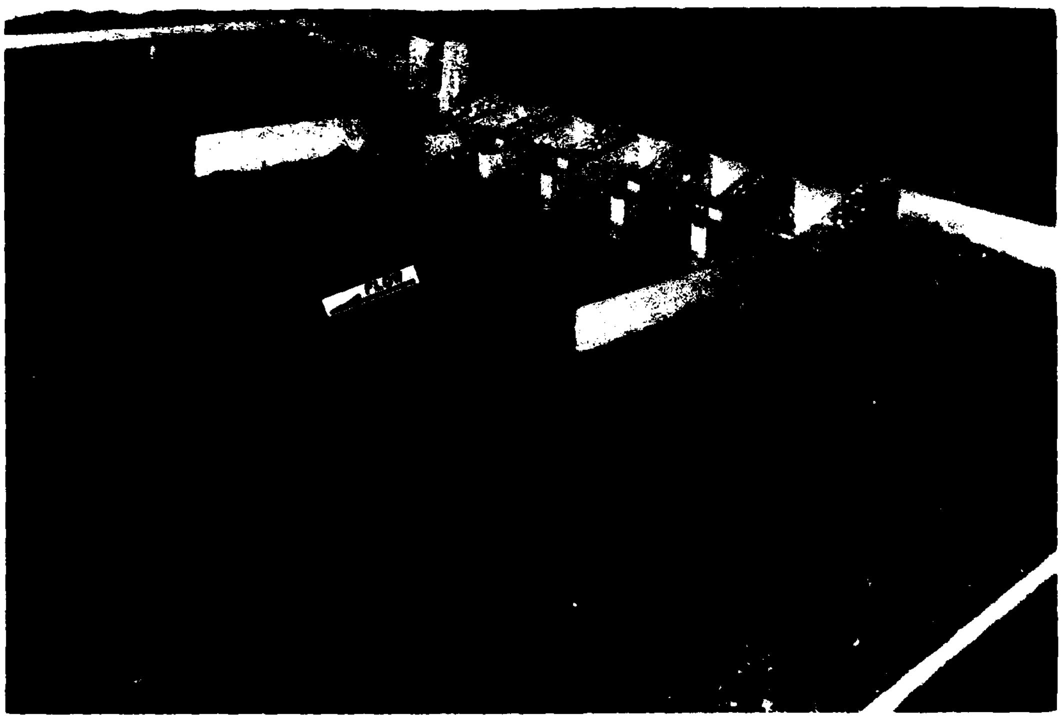
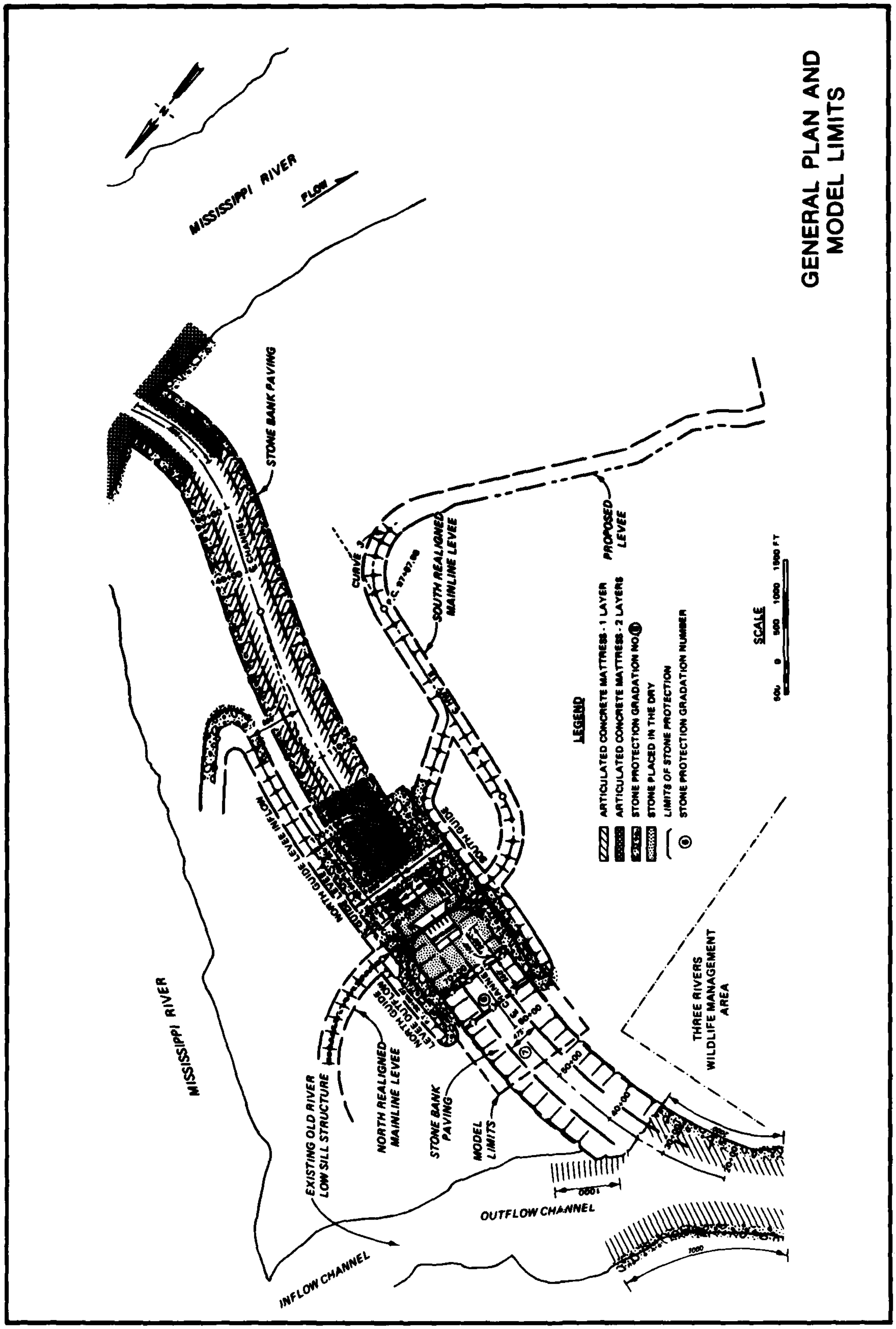


Photo 18. Recommended stilling basin design, discharge 60,000 cfs, pool el 40.8, tailwater el 24.0, one gate fully open



GENERAL PLAN AND MODEL LIMITS

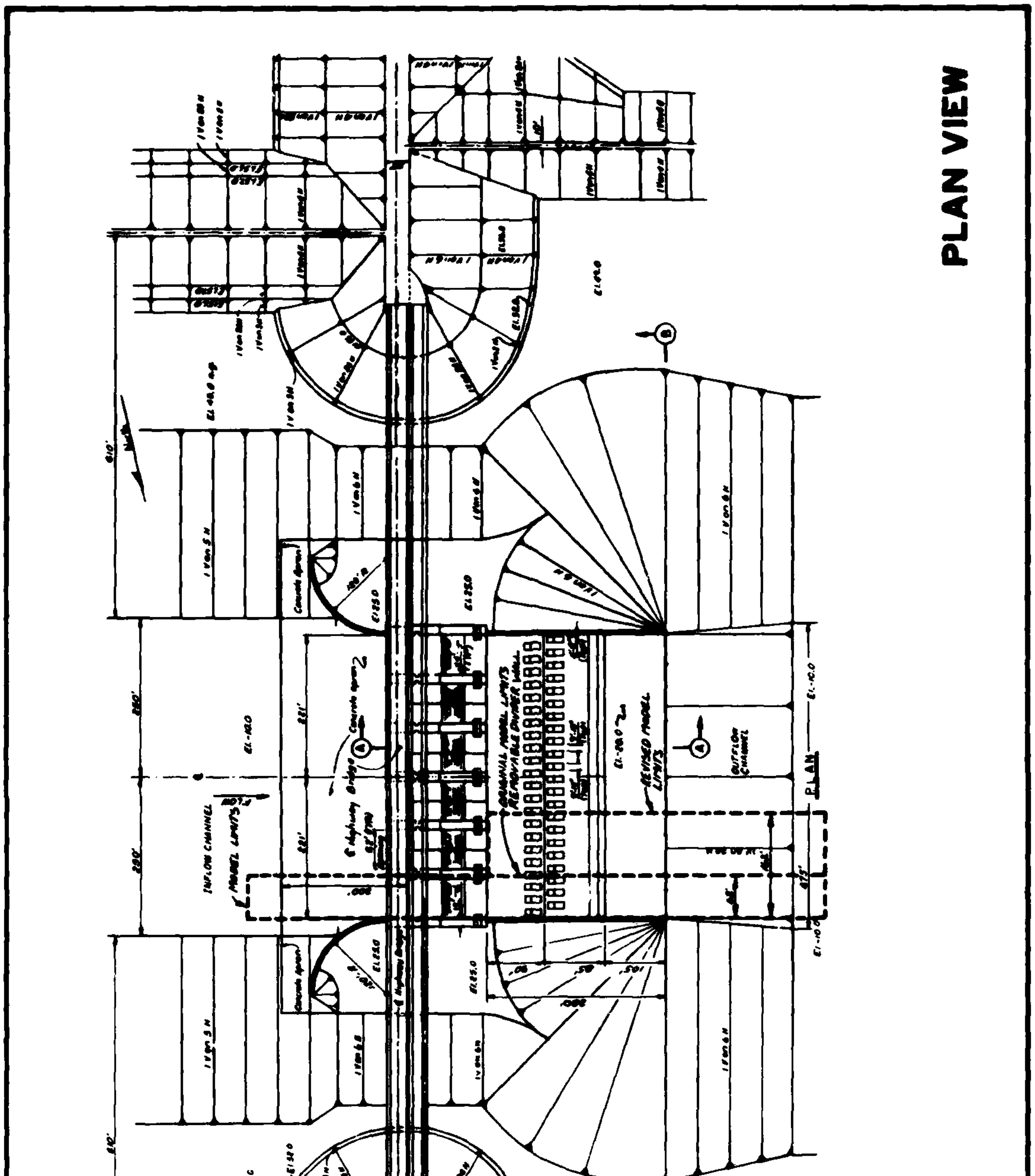
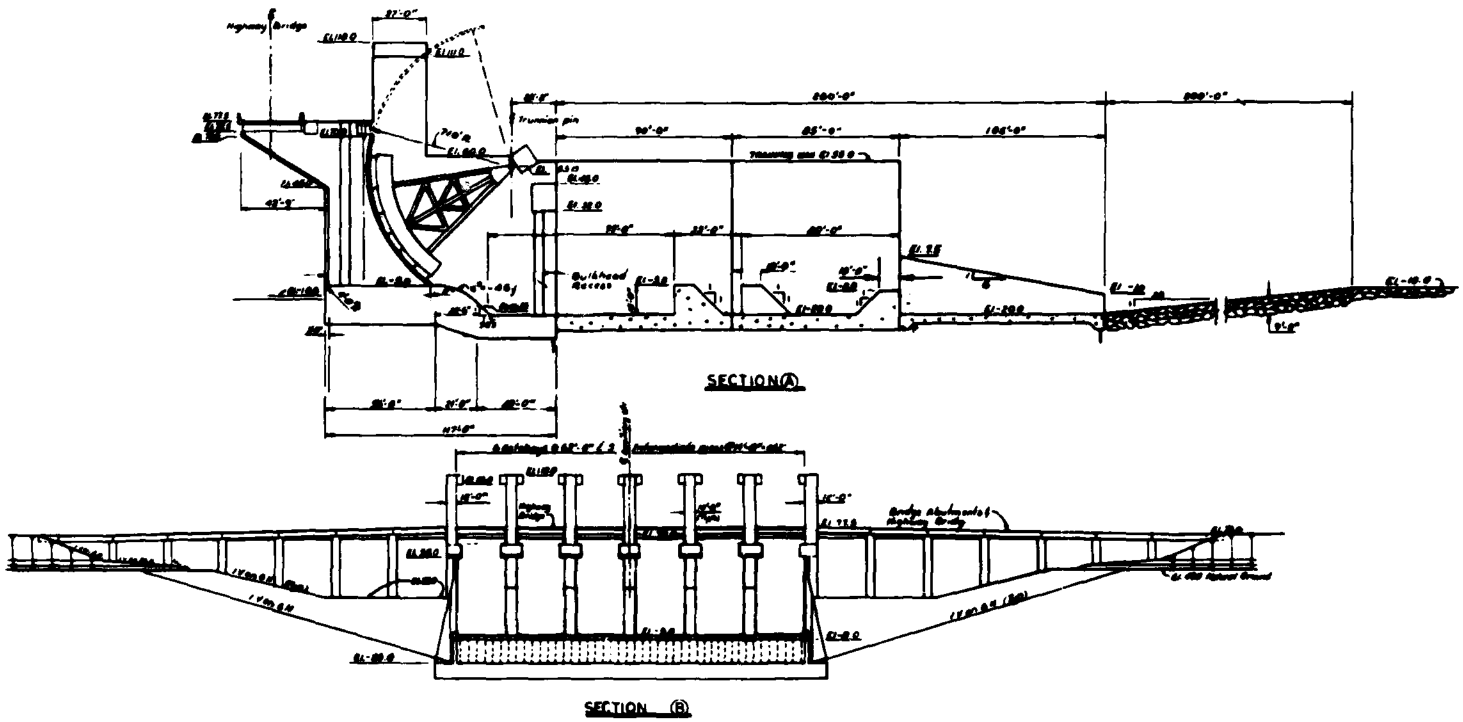


PLATE 2



TYPICAL SECTION

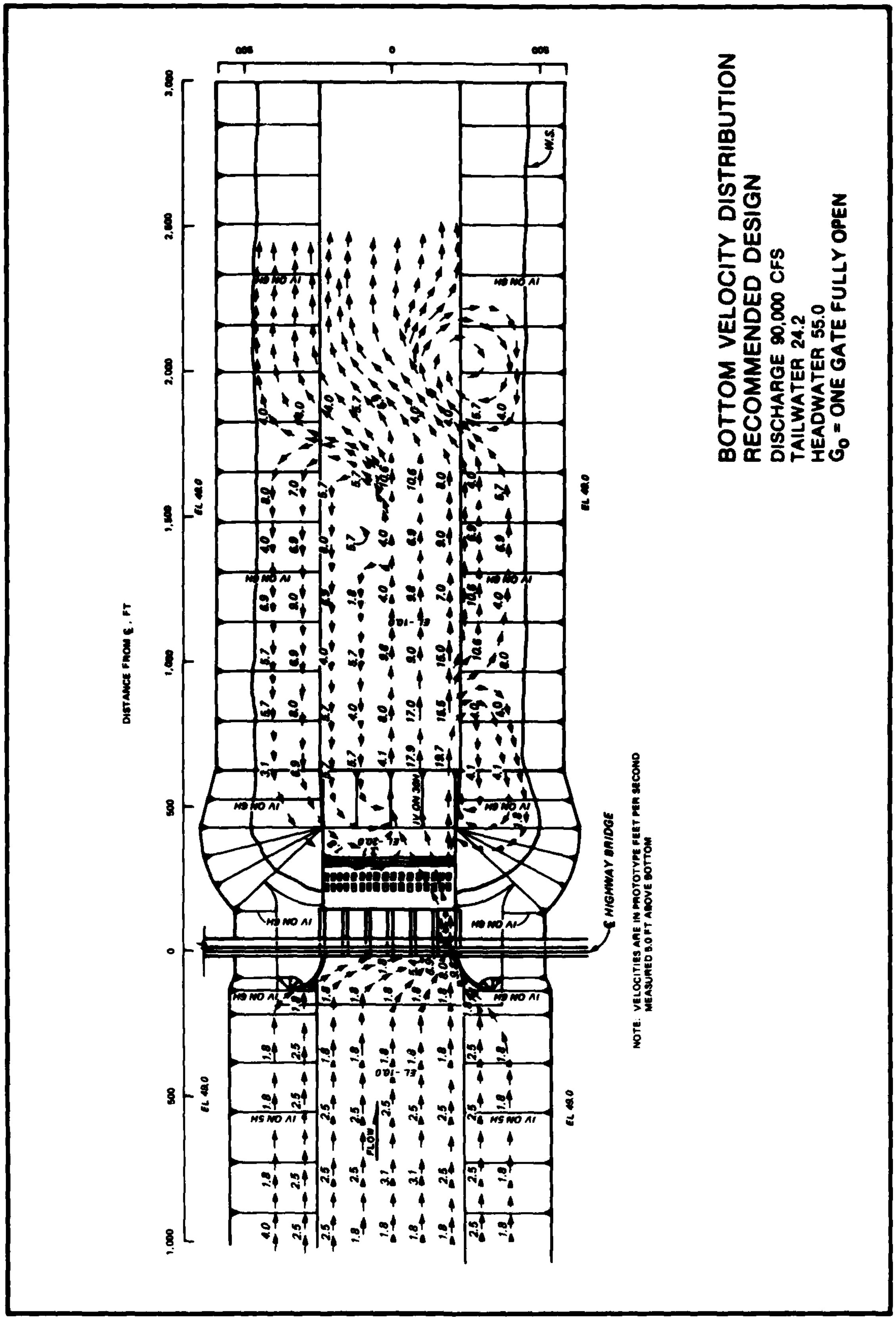
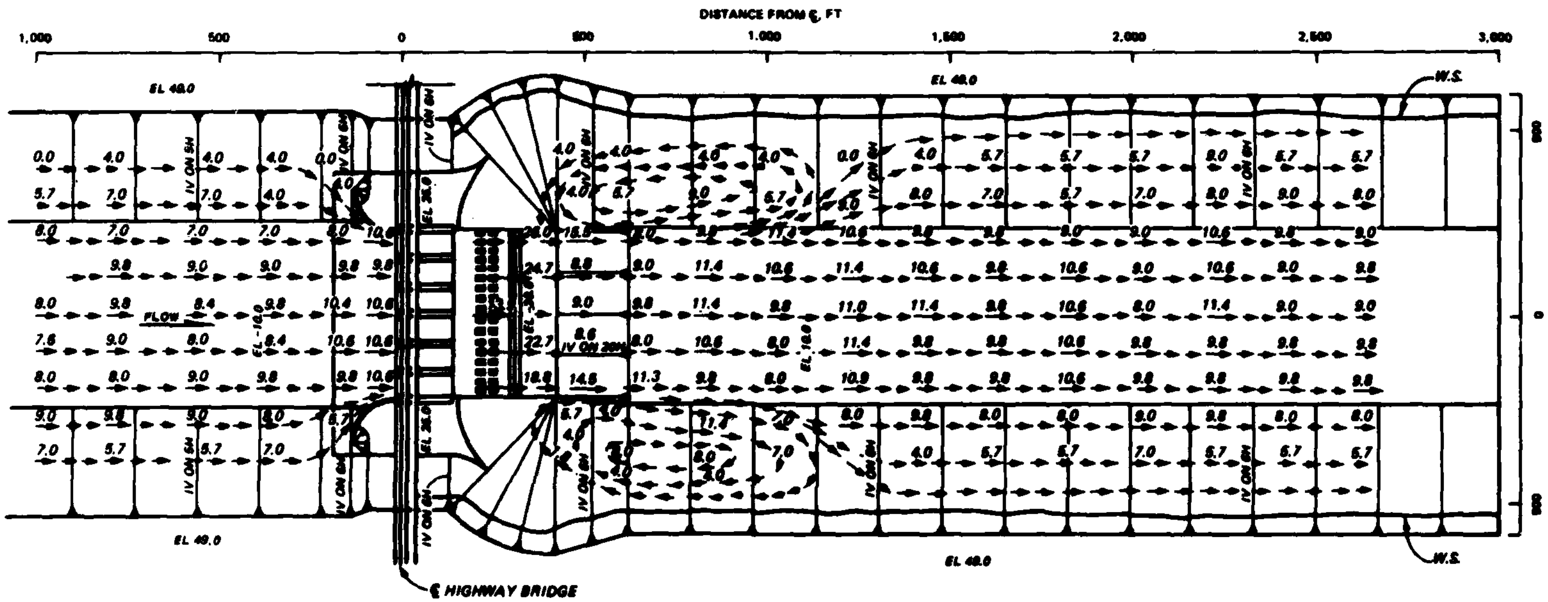

BOTTOM VELOCITY DISTRIBUTION
RECOMMENDED DESIGN
DISCHARGE 90,000 CFS
TAILWATER 24.2
HEADWATER 55.0
G_O = ONE GATE FULLY OPEN
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 5.0 FT ABOVE BOTTOM
DISTANCE FROM ℄, FT
℄ HIGHWAY BRIDGE
FLOW
W.S.
EL 48.0
EL -10.0
EL -30.0
1V ON 3H
1V ON 5H

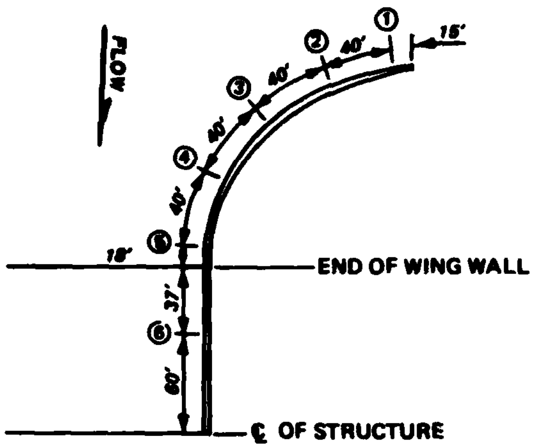
PLATE 4



NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 5.0 FT ABOVE BOTTOM

BOTTOM VELOCITY DISTRIBUTION
RECOMMENDED DESIGN

DISCHARGE 374,000 CFS
TAILWATER 38.6
HEADWATER 52.0
G_0 = 36.0 FT



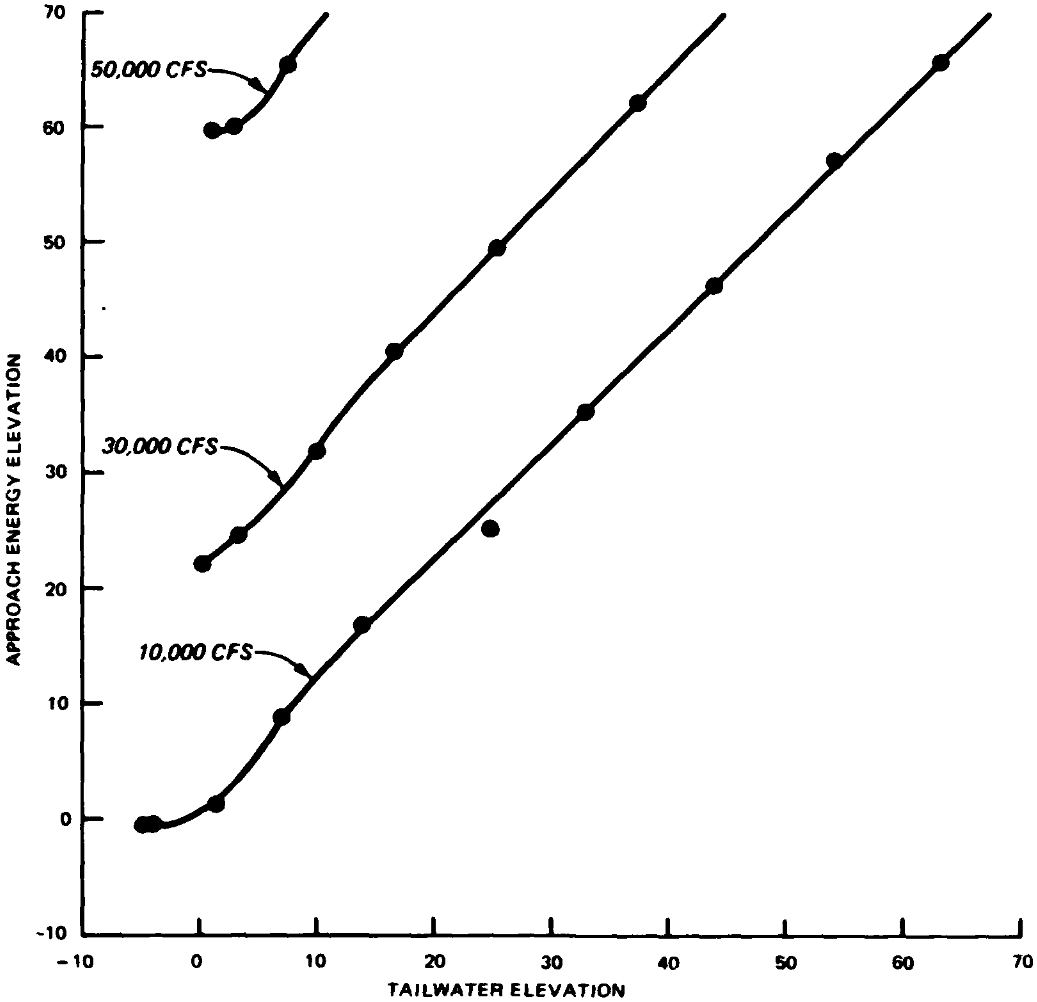
PLAN

NOTE: WATER-SURFACE ELEVATIONS BEHIND WALL ARE EQUAL TO HEADWATER ELEVATION.

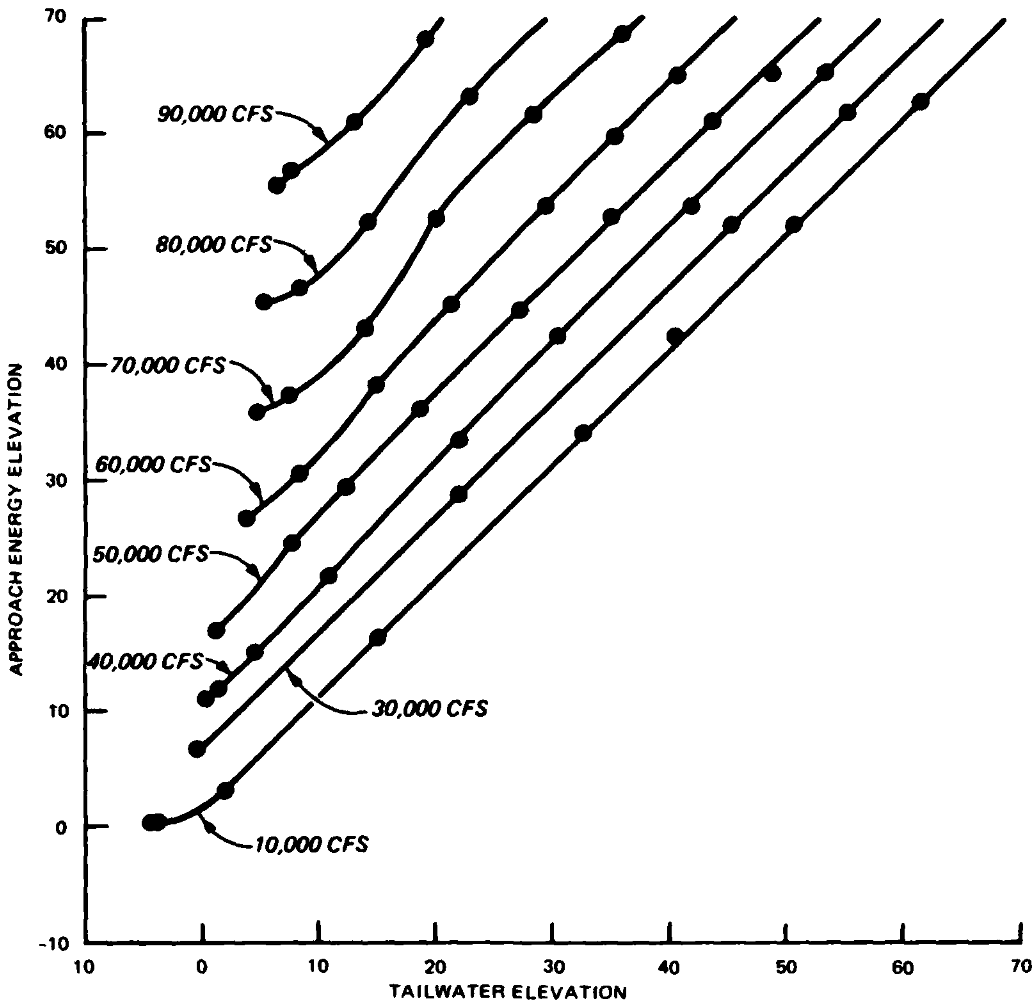
POINT OF MEASUREMENT (FLOW SIDE OF WALL)	WATER-SURFACE ELEVATION ALONG FLOW SIDE OF WALL		
	69,000 CFS*	528,000 CFS**	550,000 CFS†
UPSTREAM EDGE OF WING WALL	–	54.30	70.00
END OF WING WALL	–	39.80	64.60
1	9.55	54.50	70.00
2	10.10	52.25	69.75
3	10.00	49.00	67.75
4	9.20	43.35	64.50
5	9.00	39.65	62.65
6	4.40	45.70	65.55
℄ OF STRUCTURE	8.90	34.35	64.40

* HEADWATER = 10.0 , TAILWATER = 3.05
** HEADWATER = 52.0, TAILWATER = 27.15
† HEADWATER = 69.0, TAILWATER = 65.50

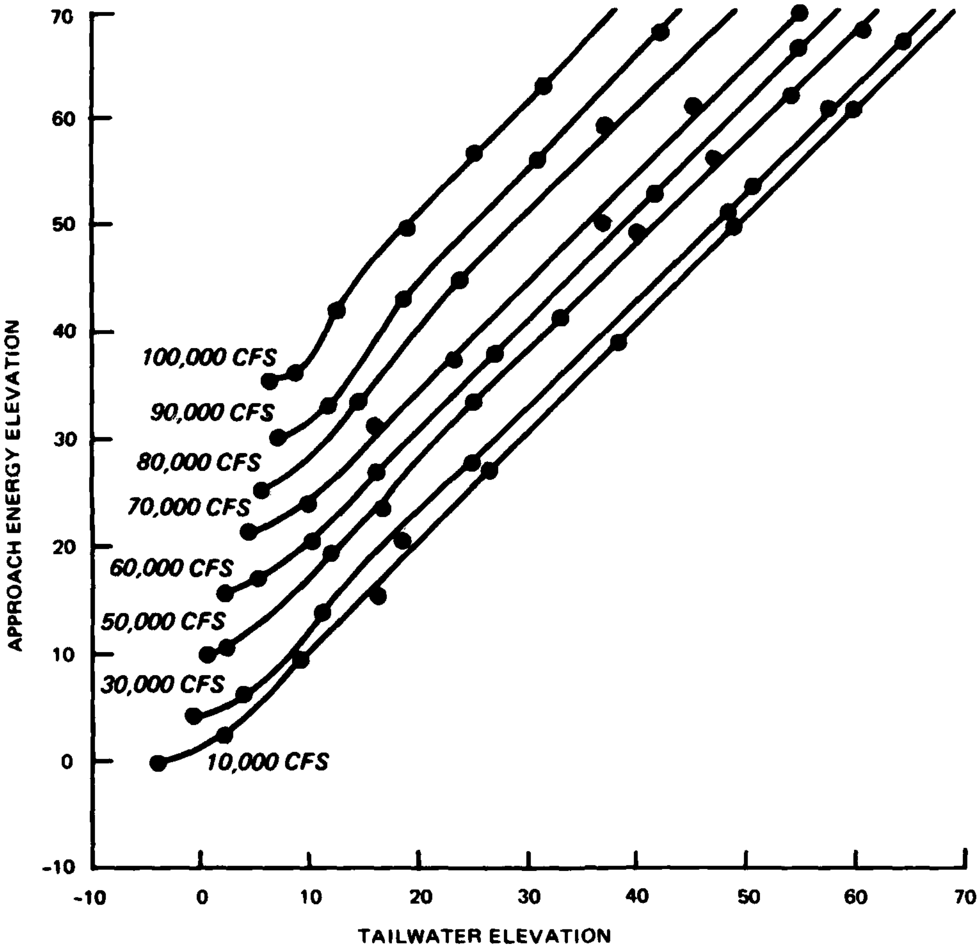
TYPE 2 APPROACH WING WALLS
WATER-SURFACE ELEVATION



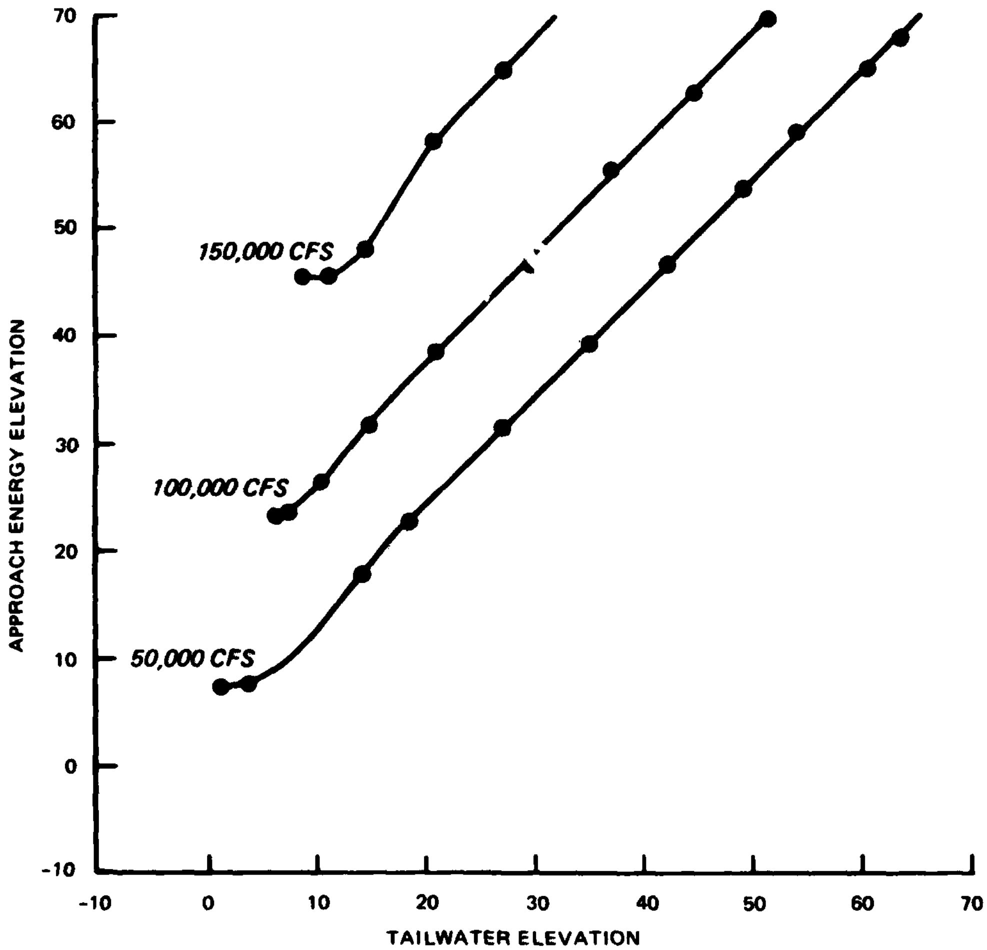
CALIBRATION DATA FOR CONTROLLED FLOW RECOMMENDED DESIGN
G_o = 2.5 FT



CALIBRATION DATA FOR CONTROLLED FLOW RECOMMENDED DESIGN G_o = 5.0 FT

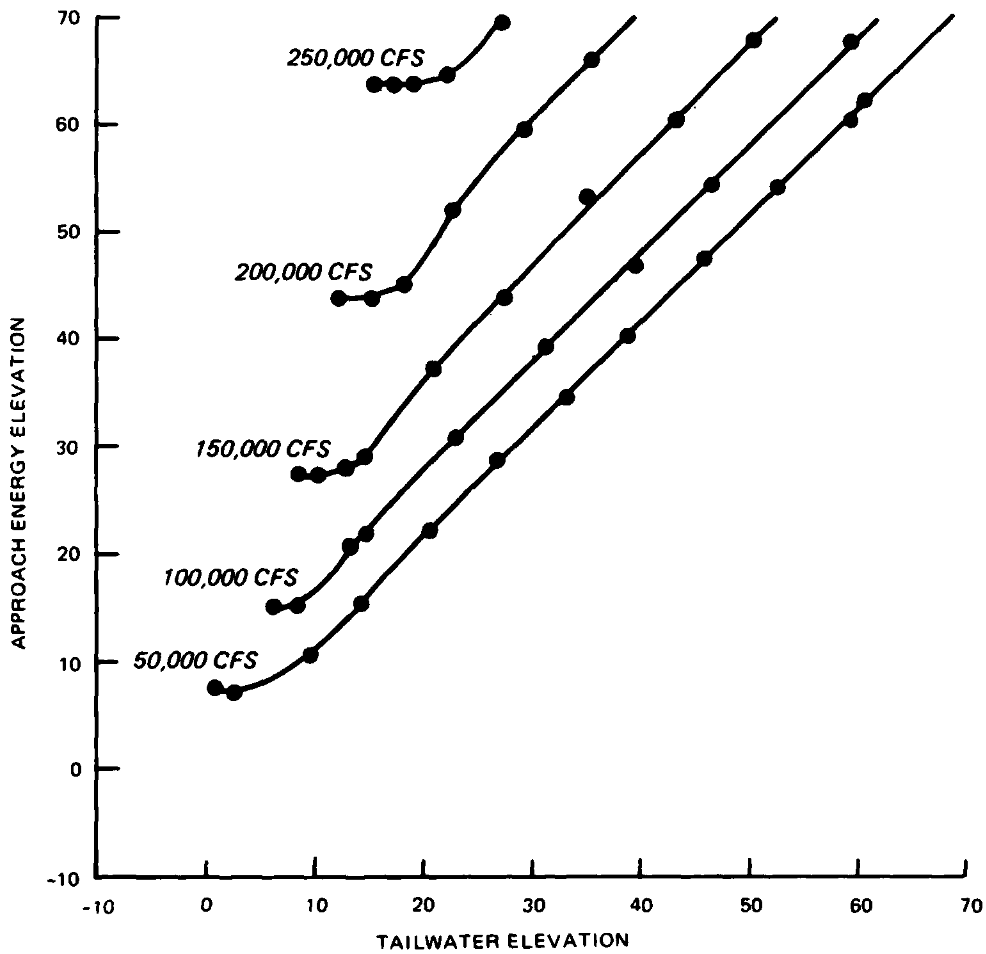


CALIBRATION DATA FOR CONTROLLED FLOW RECOMMENDED DESIGN
G_0 = 7.5 FT



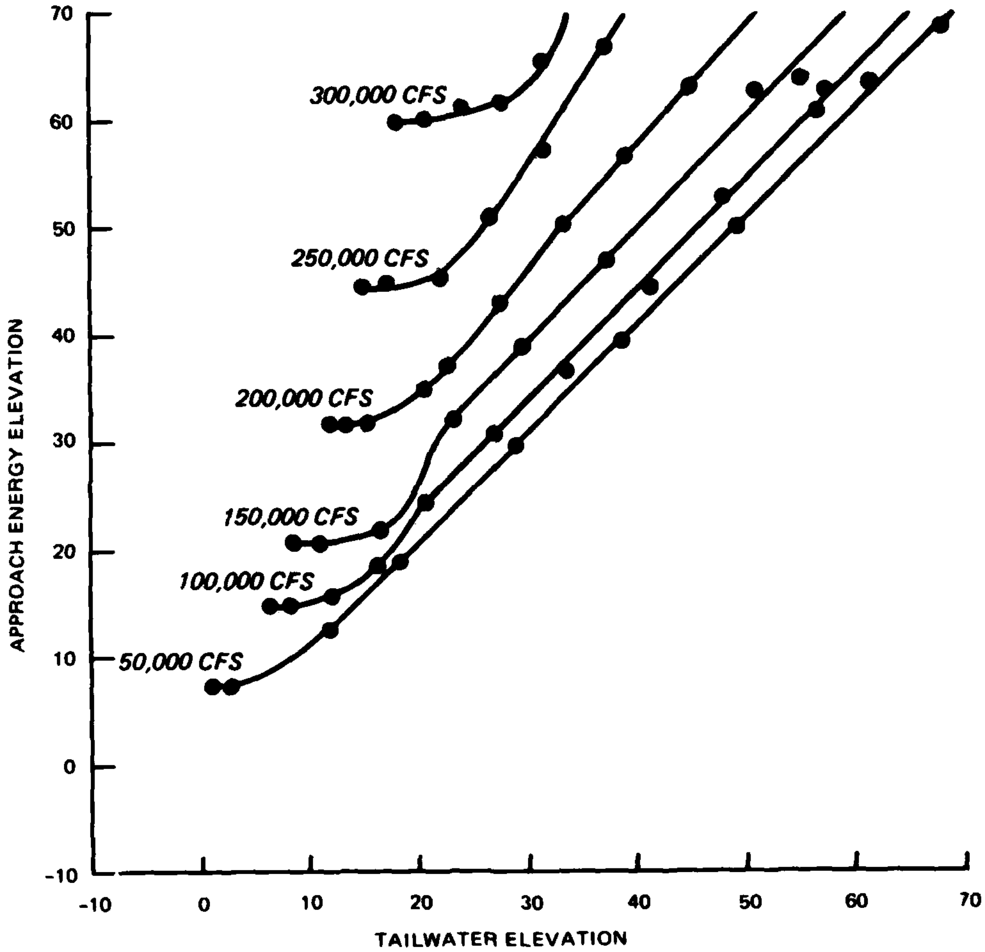
CALIBRATION DATA FOR CONTROLLED FLOW RECOMMENDED DESIGN

G_o = 10.0 FT



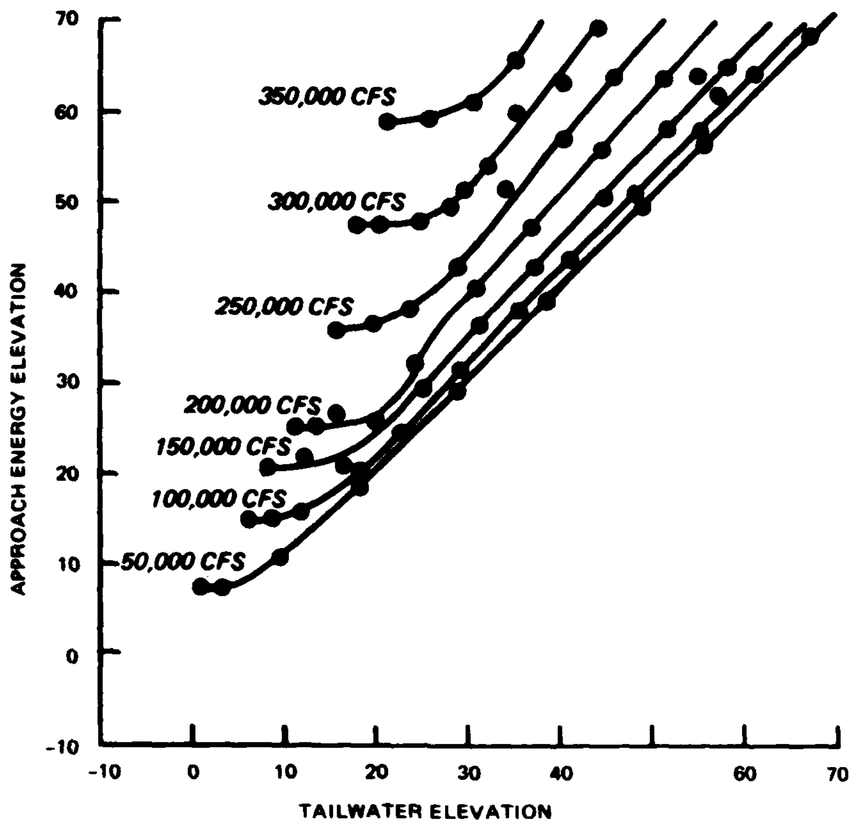
CALIBRATION DATA FOR CONTROLLED FLOW RECOMMENDED DESIGN

G_o = 15.0 FT

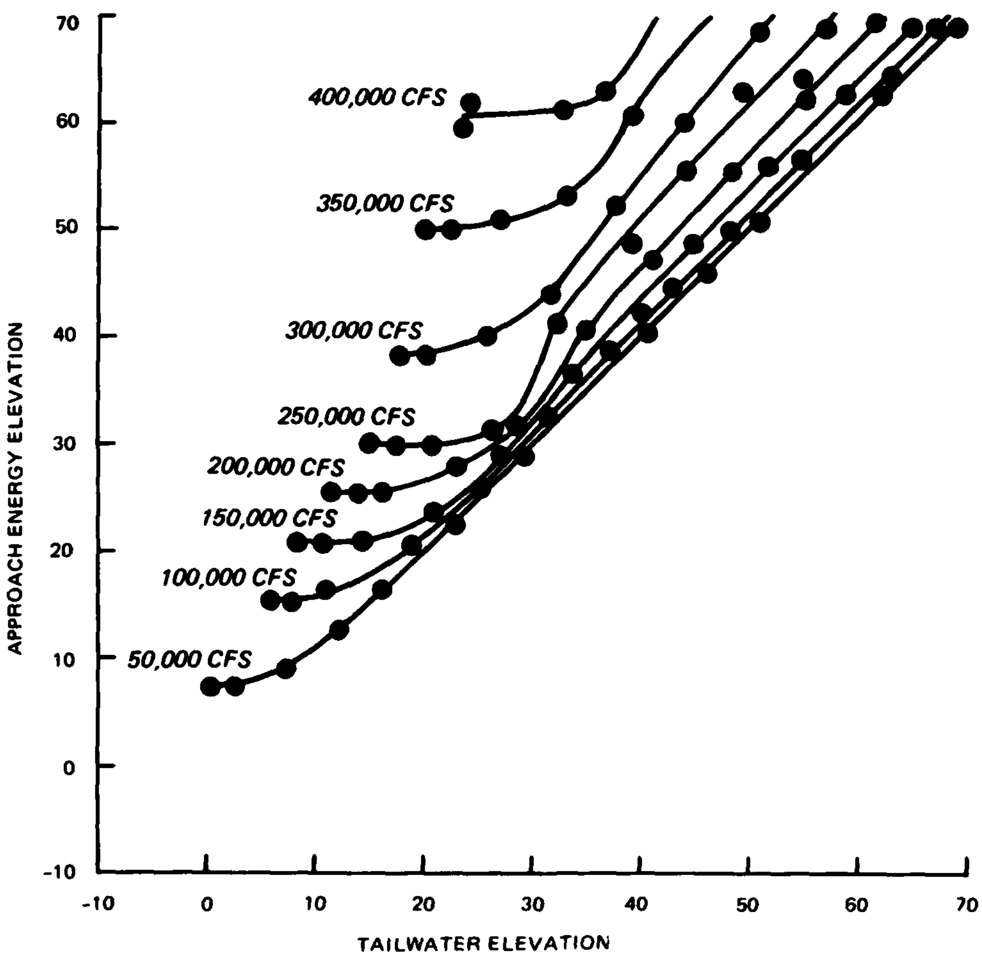


CALIBRATION DATA FOR CONTROLLED FLOW RECOMMENDED DESIGN

G_o = 20.0 FT



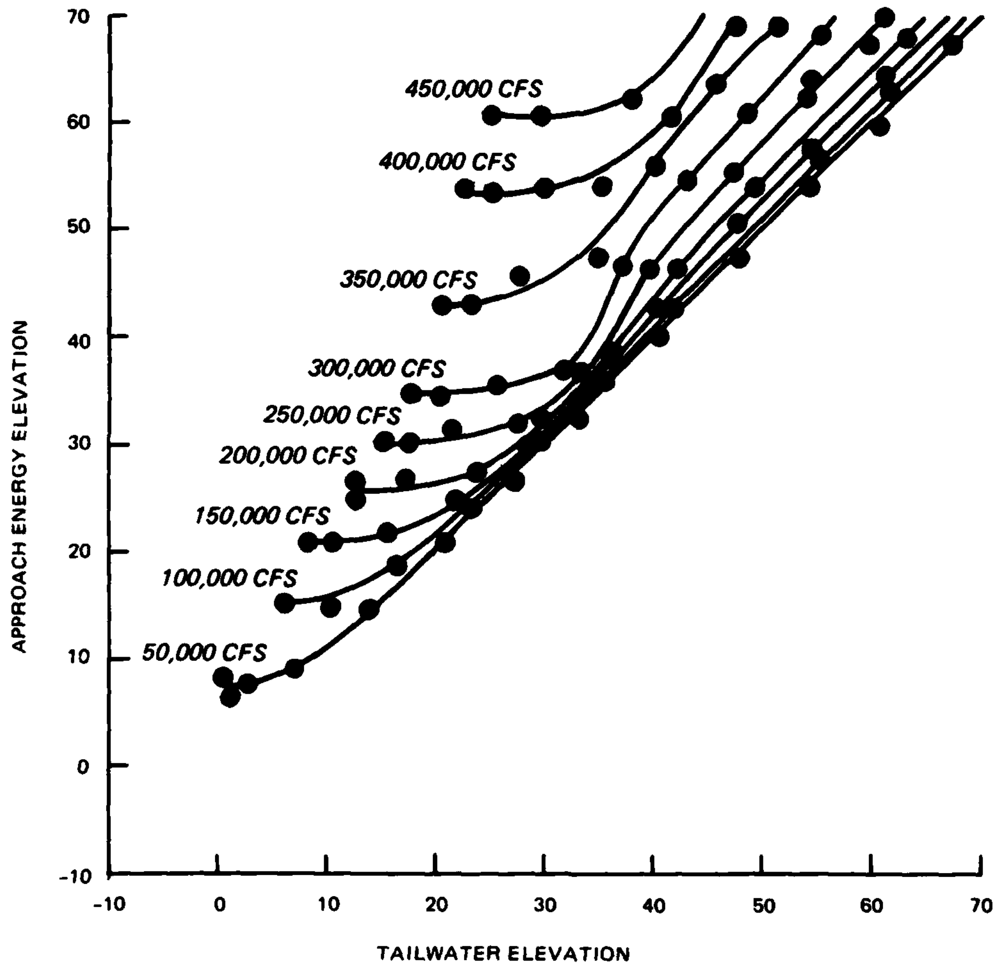
CALIBRATION DATA FOR CONTROLLED FLOW RECOMMENDED DESIGN
G_0 = 25.0 FT



CALIBRATION DATA FOR CONTROLLED FLOW RECOMMENDED DESIGN

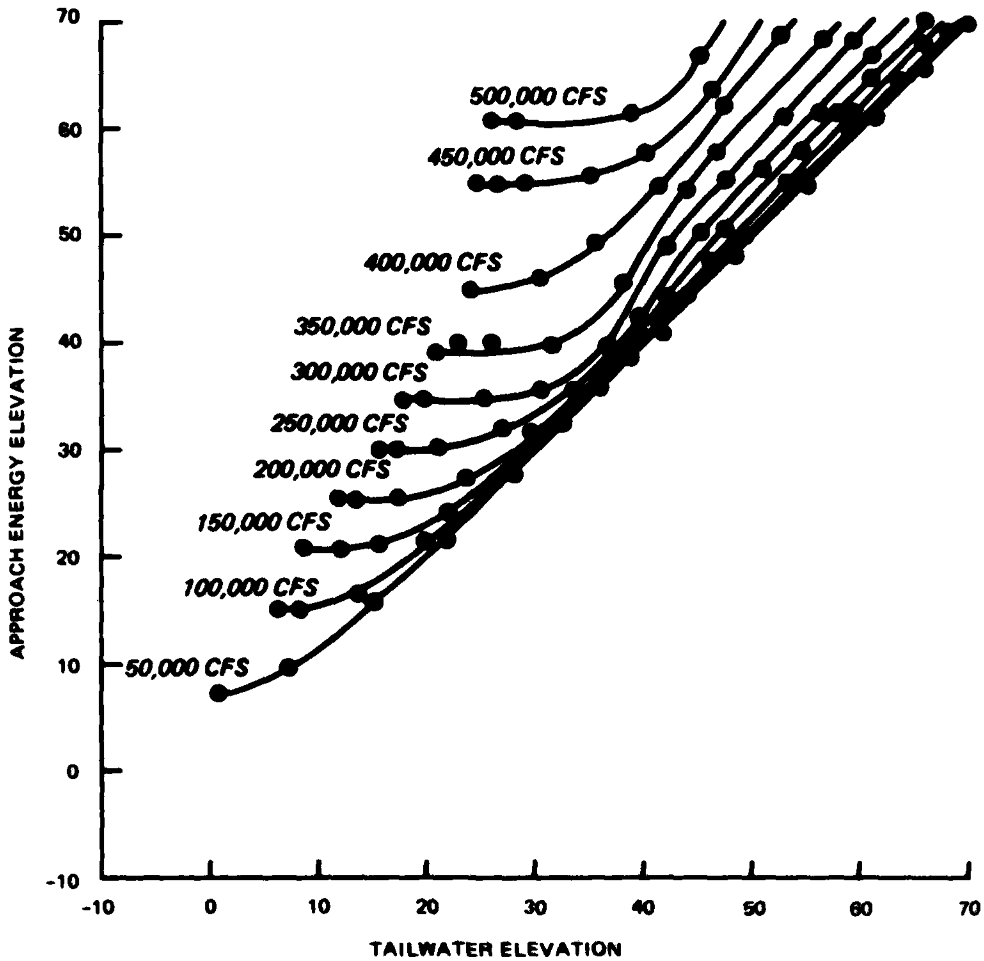
G_o = 30.0 FT

PLATE 14

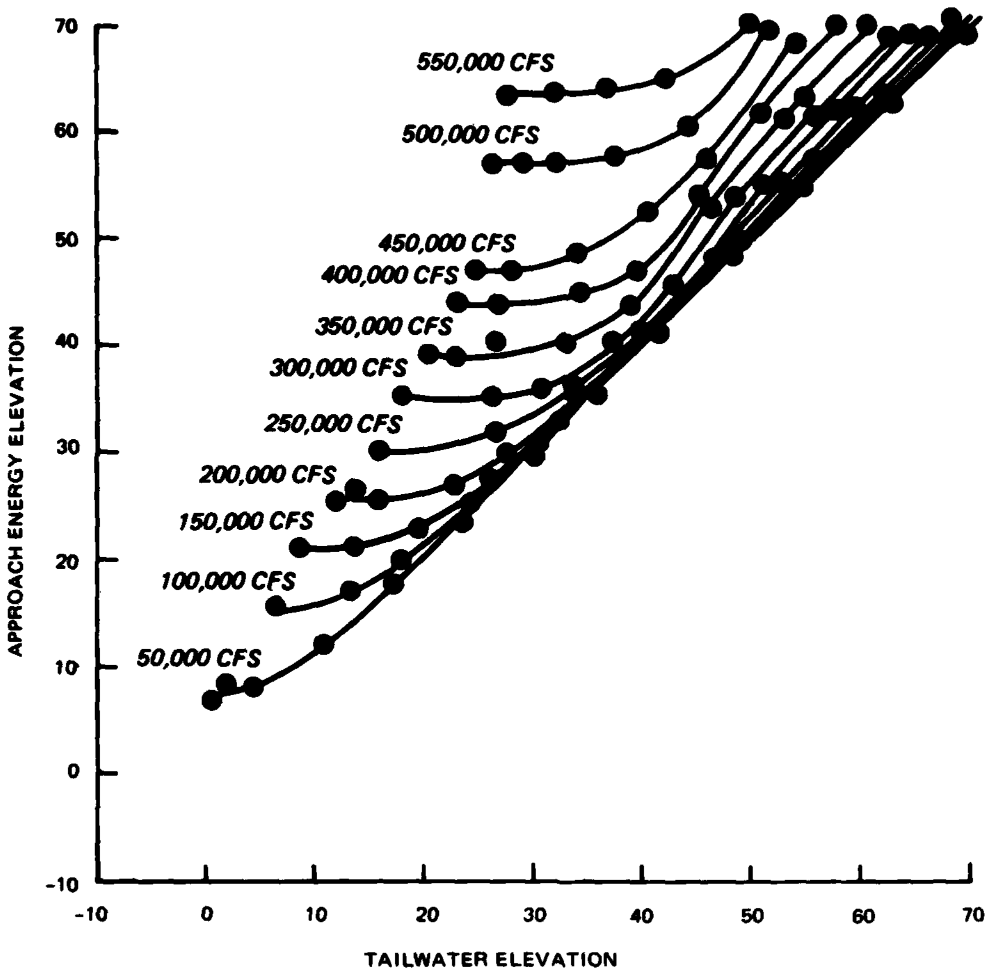


CALIBRATION DATA FOR CONTROLLED FLOW RECOMMENDED DESIGN

G_o = 35.0 FT

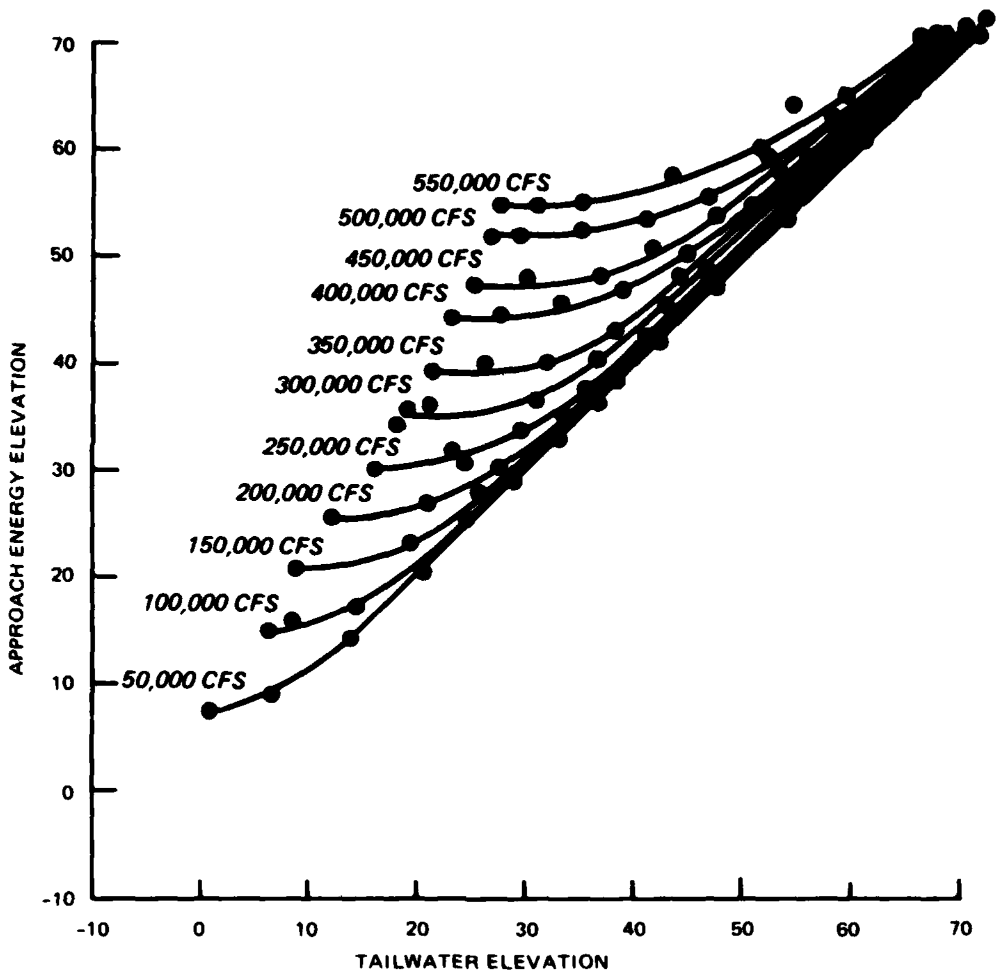


CALIBRATION DATA FOR
CONTROLLED FLOW
RECOMMENDED DESIGN
G_o = 40.0 FT

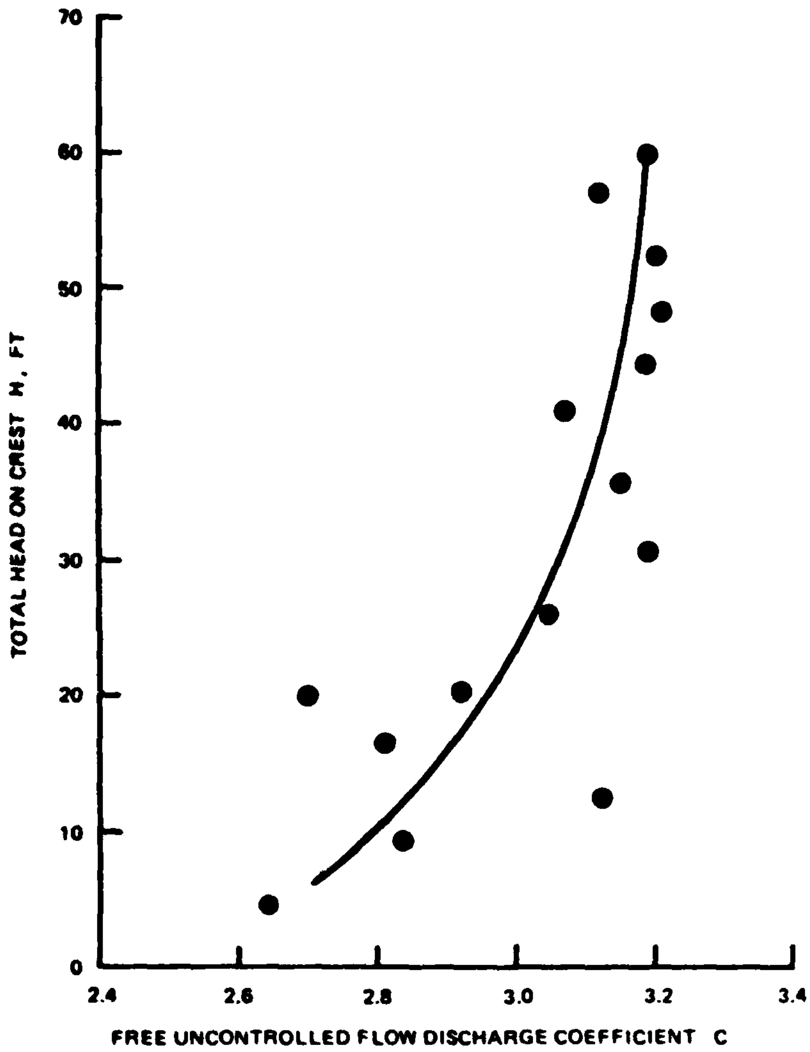


CALIBRATION DATA FOR CONTROLLED FLOW RECOMMENDED DESIGN

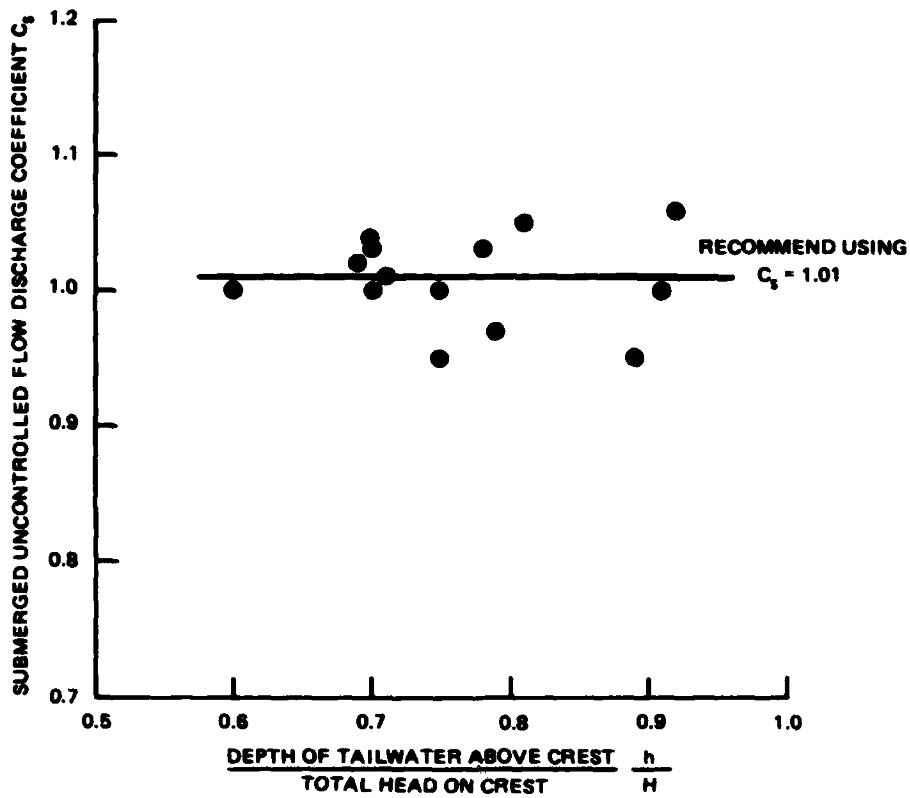
$G_o = 45.0$ FT



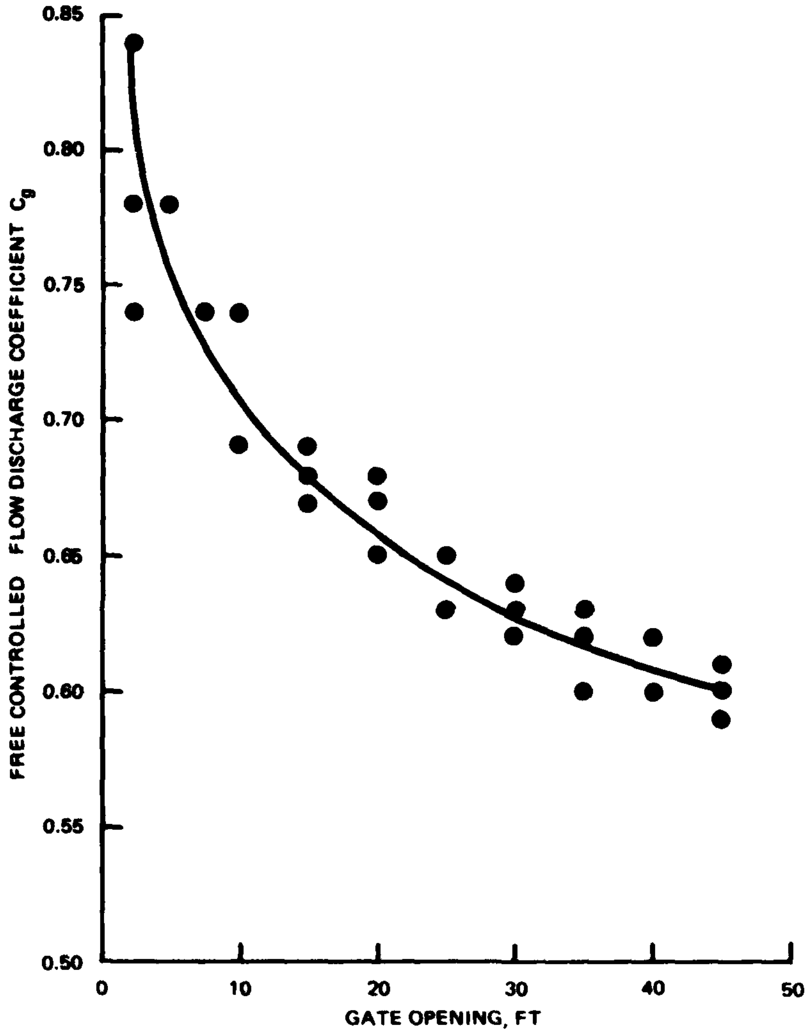
CALIBRATION DATA FOR UNCONTROLLED FLOW RECOMMENDED DESIGN



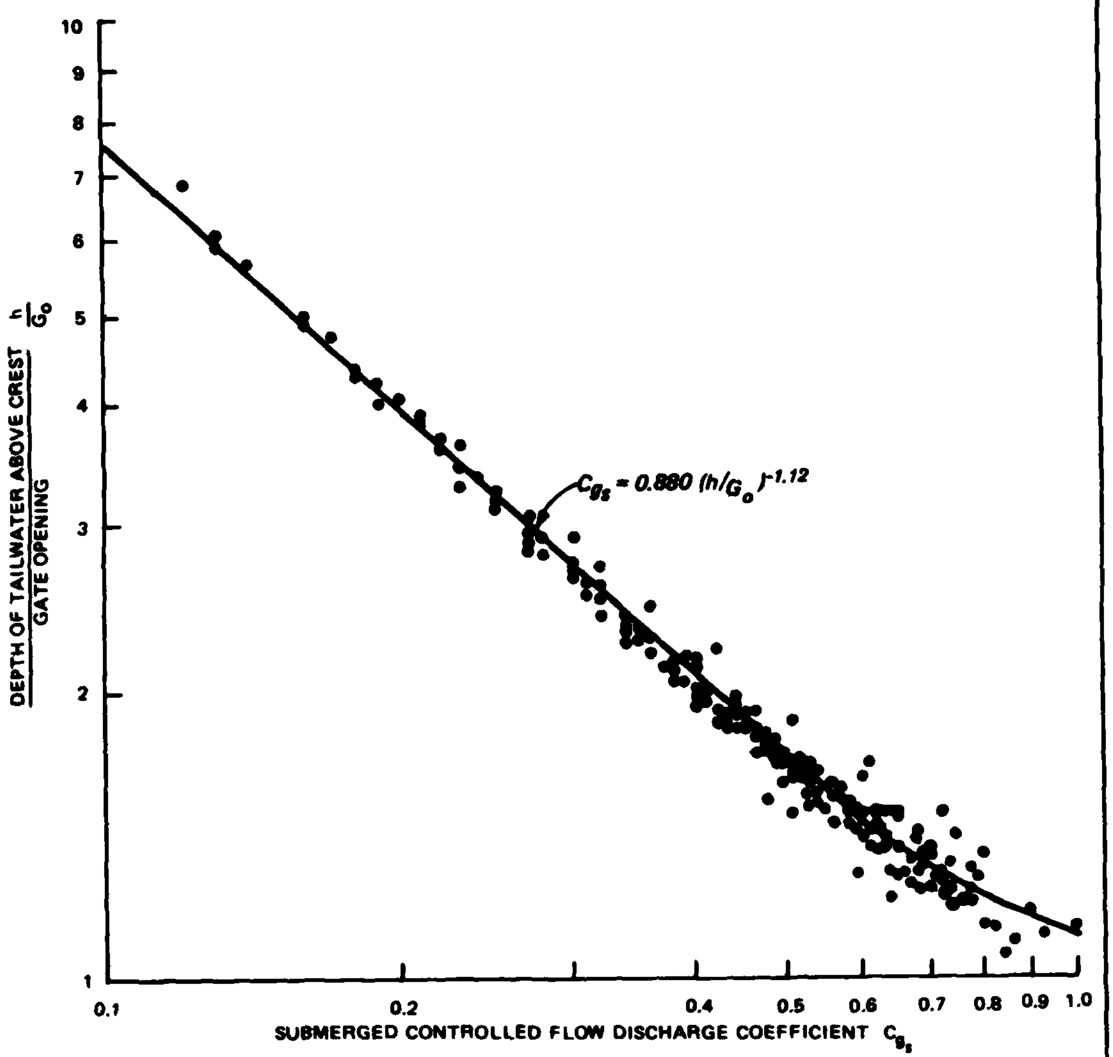
DISCHARGE COEFFICIENT FOR
FREE UNCONTROLLED FLOW



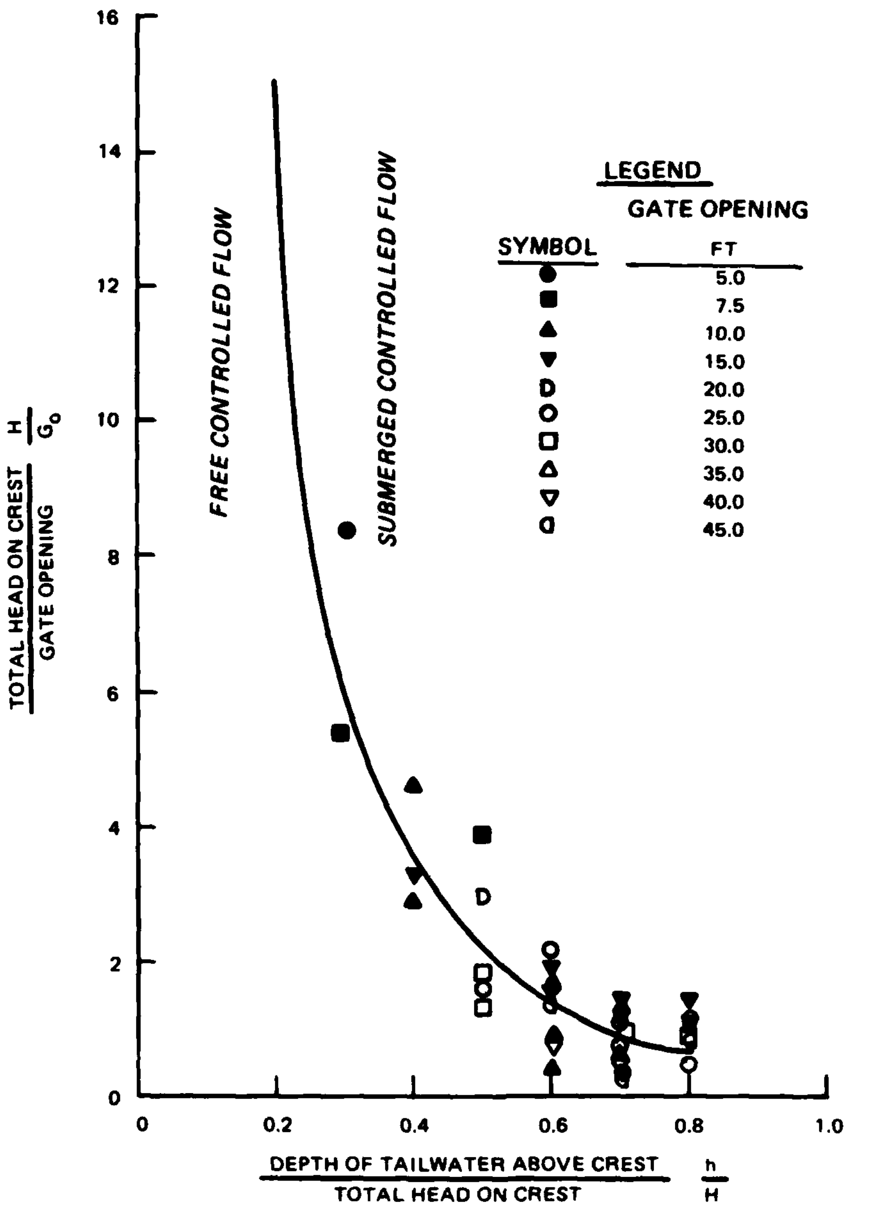
DISCHARGE COEFFICIENT FOR SUBMERGED UNCONTROLLED FLOW



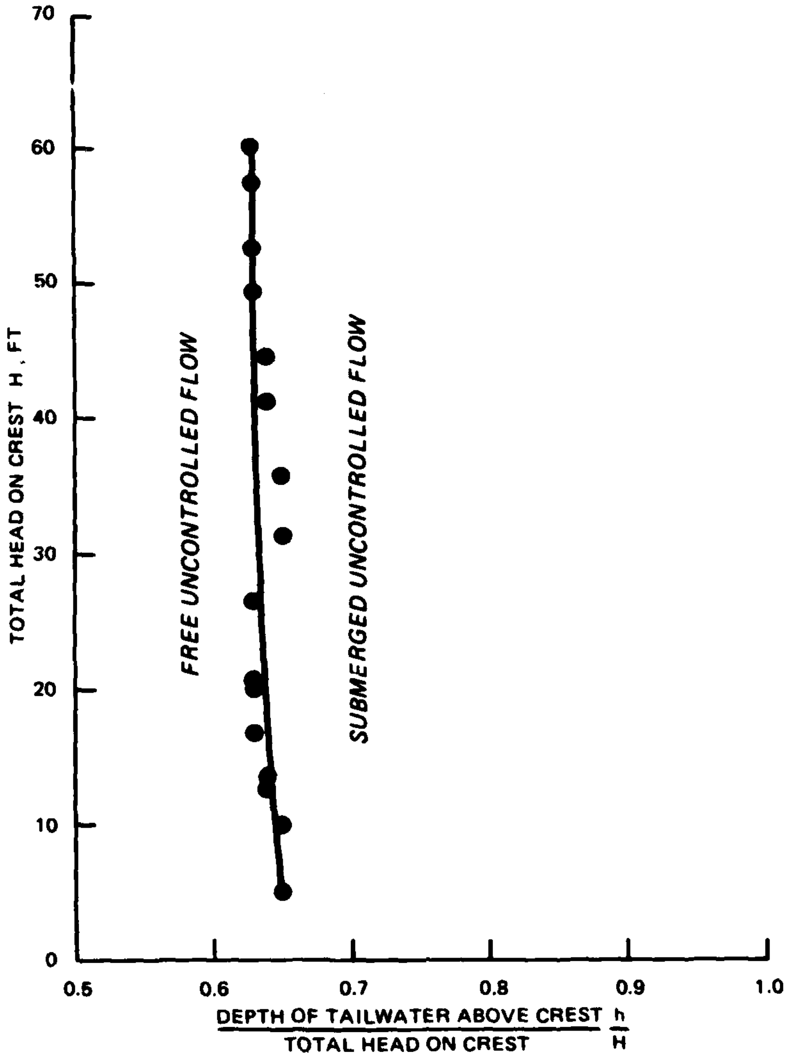
DISCHARGE COEFFICIENT FOR FREE CONTROLLED FLOW



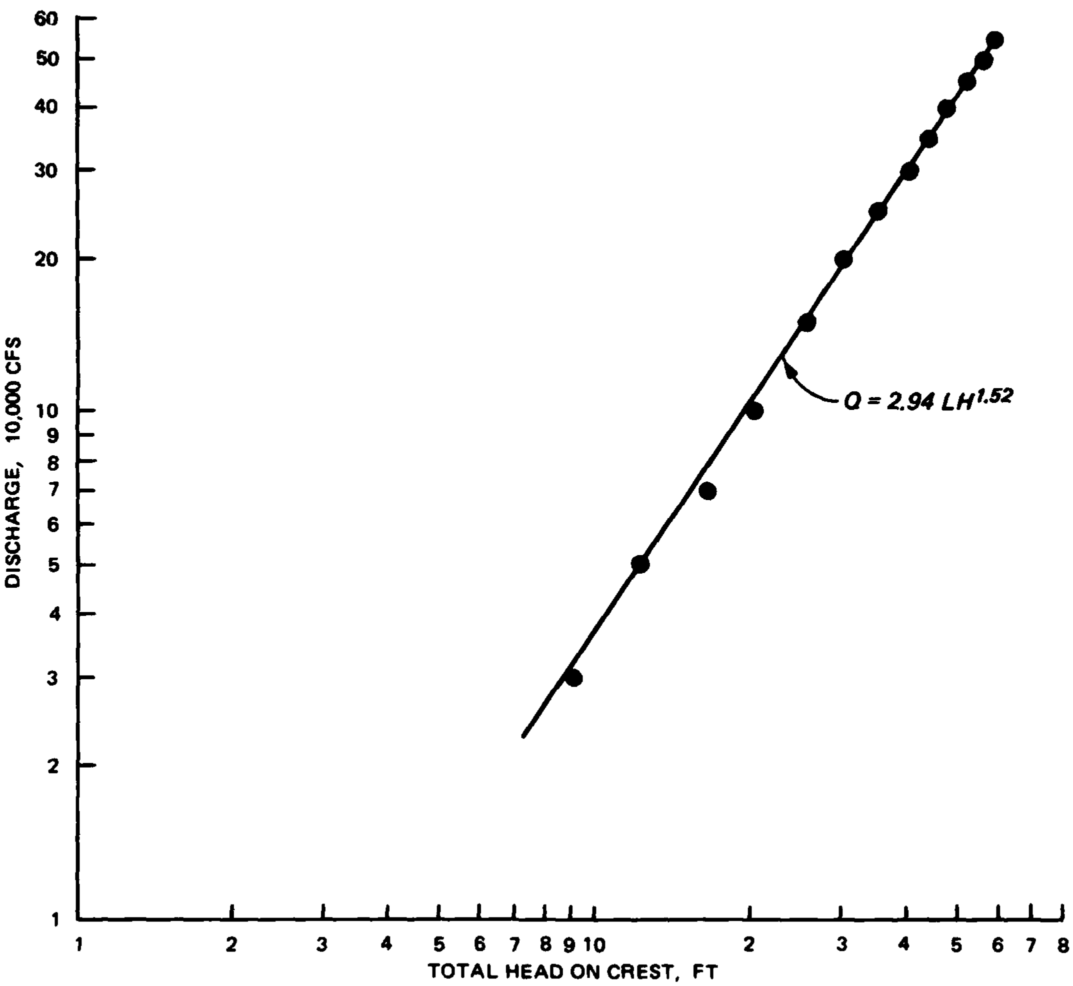
DISCHARGE COEFFICIENT FOR SUBMERGED CONTROLLED FLOW



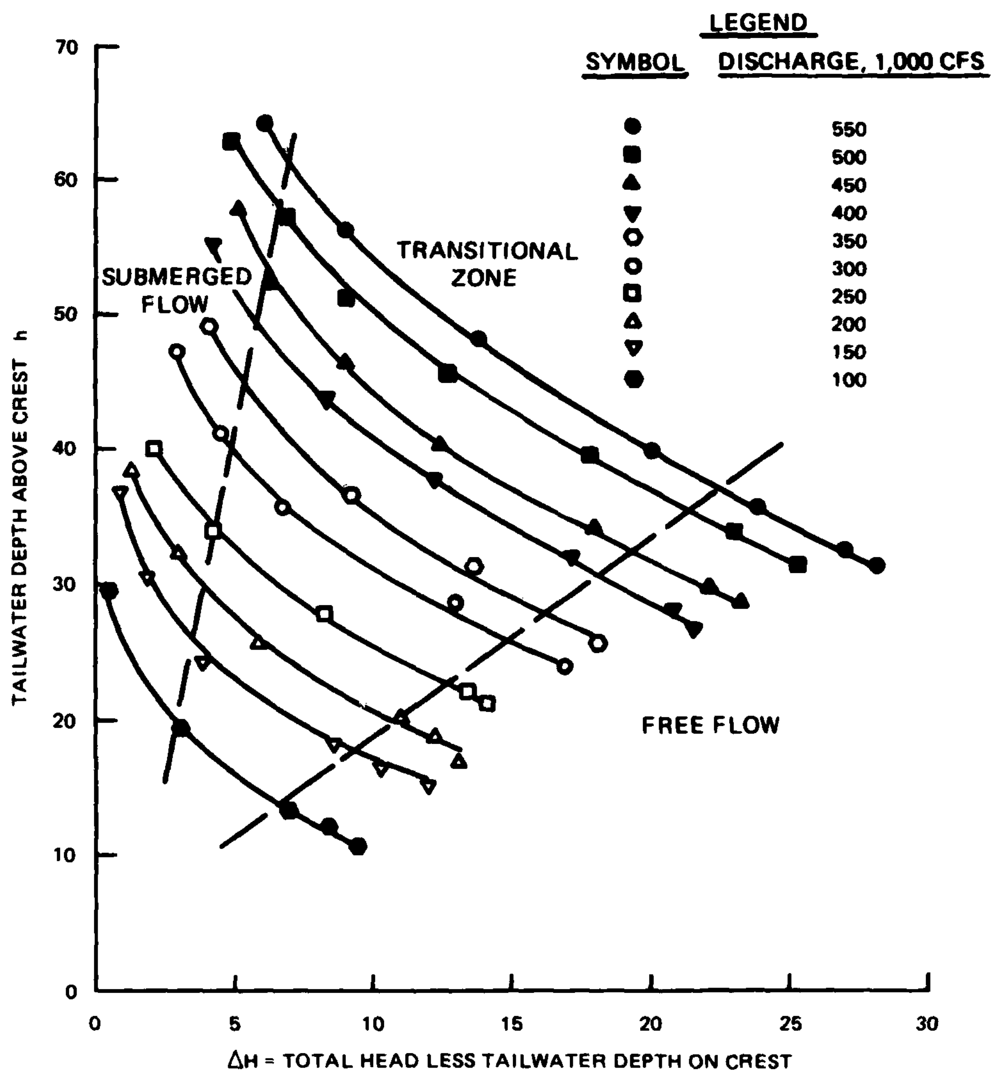
CONTROLLED FLOW REGIMES



UNCONTROLLED FLOW REGIMES

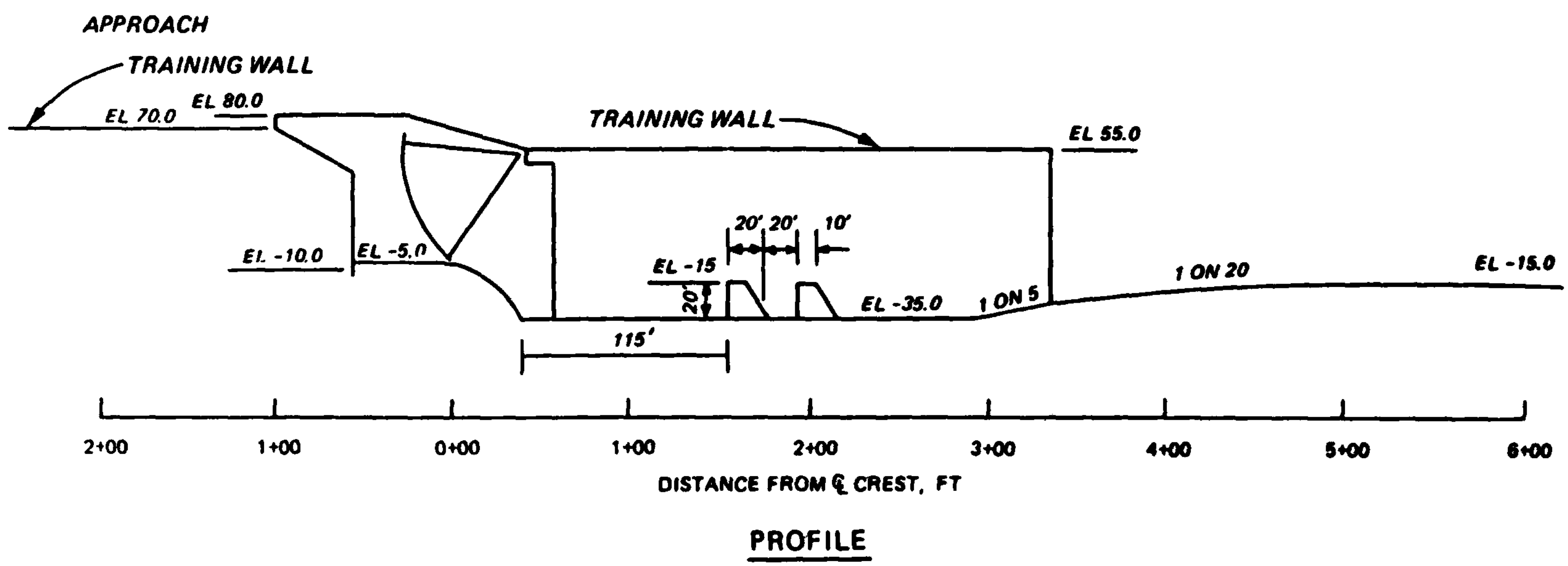


DISCHARGE - HEAD RELATIONSHIP FOR FREE UNCONTROLLED FLOW

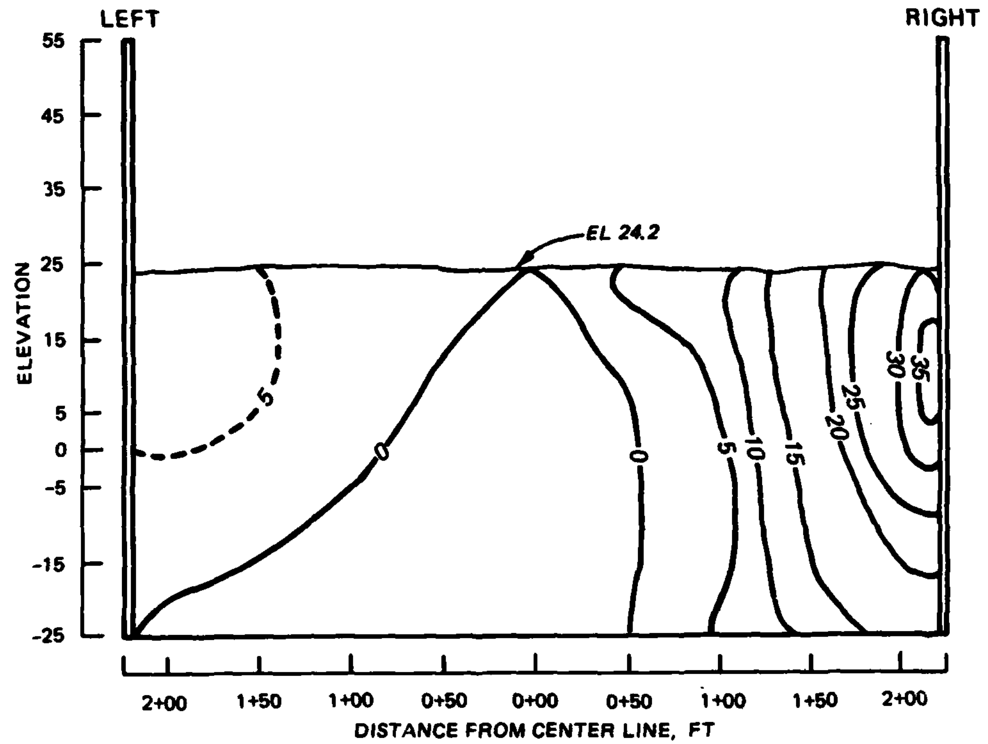


SWELLHEAD - DISCHARGE - TAILWATER ELEVATION RE[illegible]TION

FREE AND SUBMERGED UNC[illegible] ROLLED FLOW



ORIGINAL DESIGN
STILLING BASIN



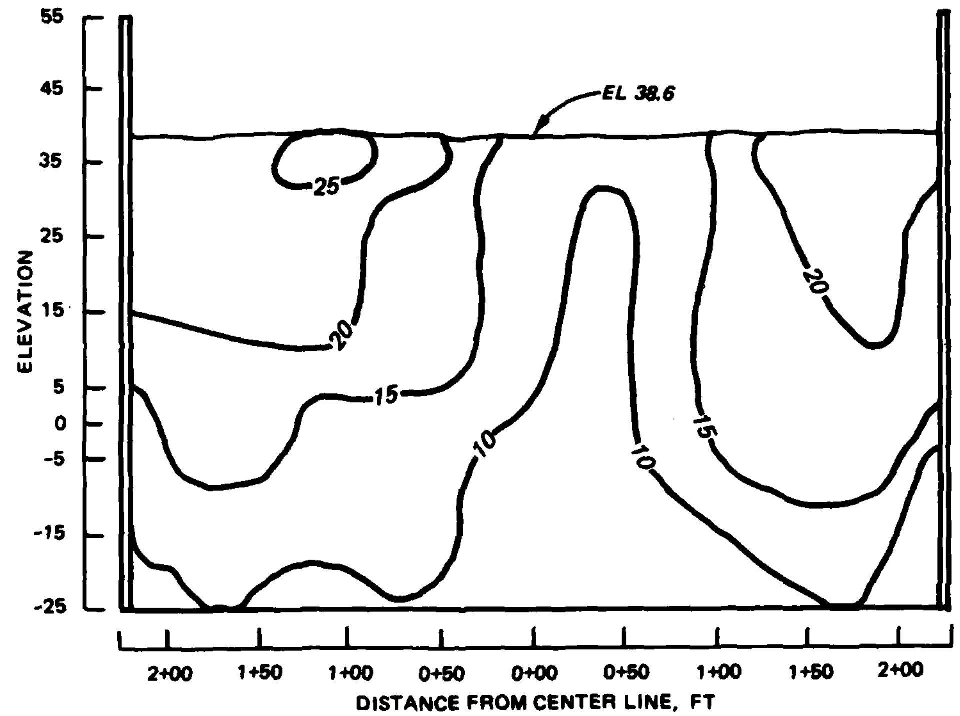
LEGEND

- —— DOWNSTREAM
- - - - UPSTREAM

DISCHARGE	90,000 CFS
HEADWATER EL	55.0
TAILWATER EL	24.2

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND
APRON EL -35.0; BAFFLE HEIGHT = 20 FT

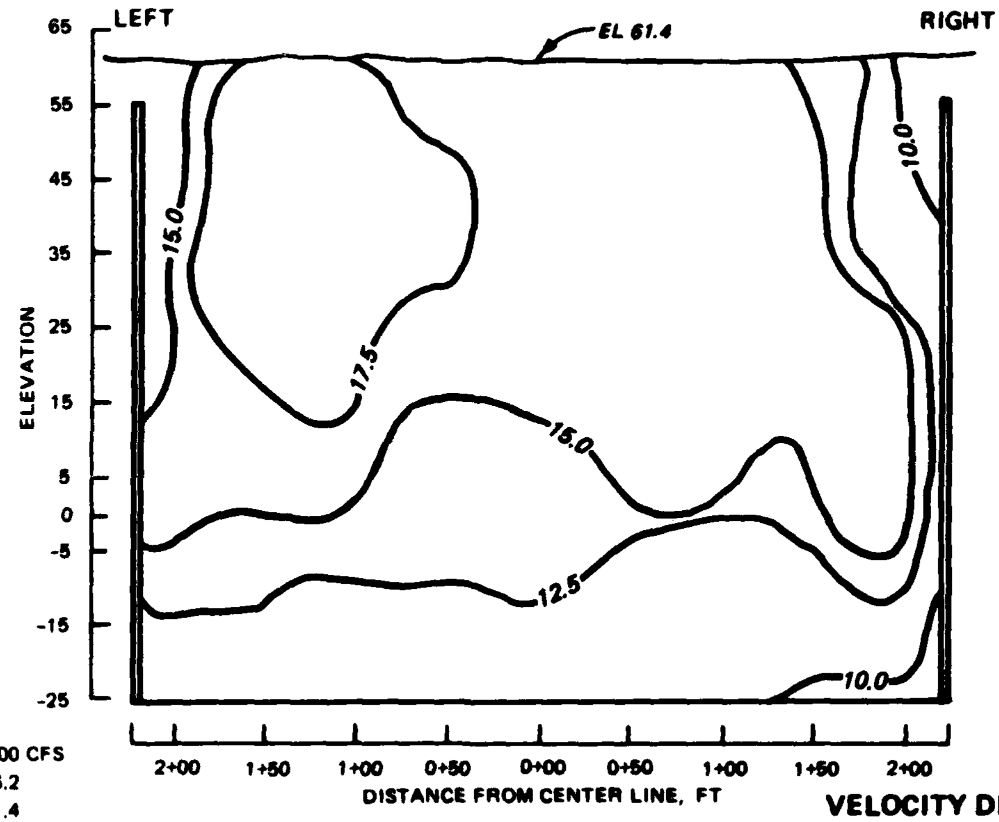
VELOCITY DISTRIBUTION
AT THE END OF STILLING BASIN
TYPE 1 (ORIGINAL) STILLING BASIN APRON
LOOKING DOWNSTREAM
ONE SIDE GATE FULLY OPEN



DISCHARGE	374,000 CFS
HEADWATER EL	52.0
TAILWATER EL	38.6

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND
APRON EL -35.0; BAFFLE HEIGHT = 20 FT

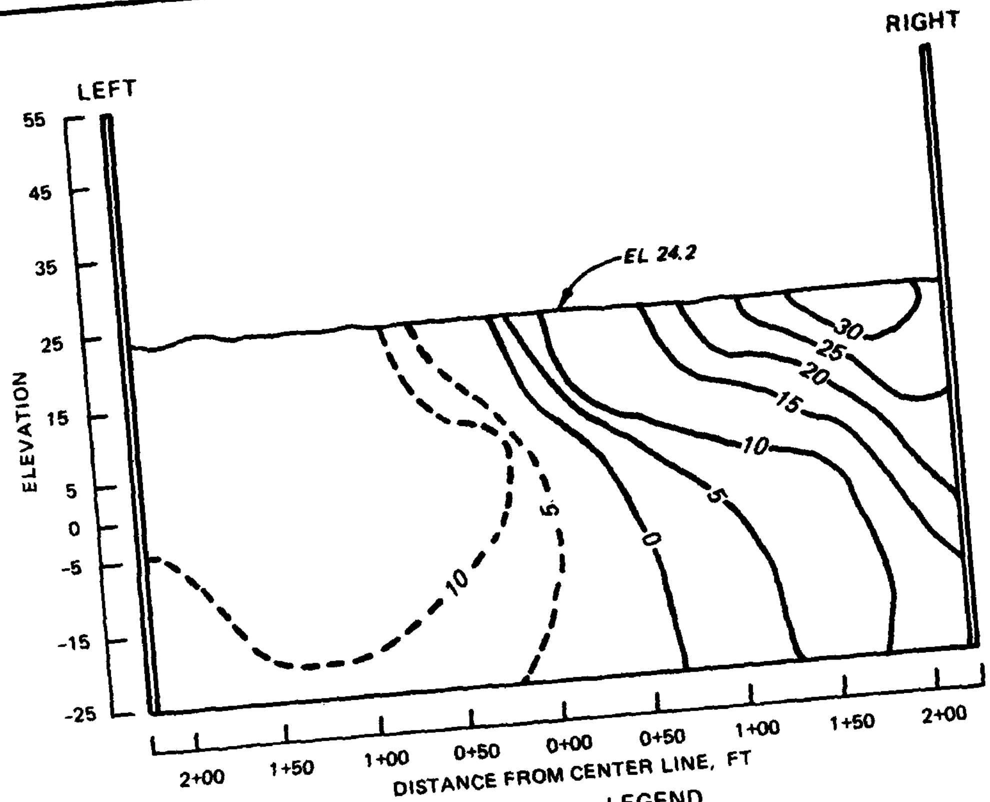
VELOCITY DISTRIBUTION
AT THE END OF STILLING BASIN
TYPE 1 (ORIGINAL) STILLING BASIN APRON
LOOKING DOWNSTREAM
G_o = 36.0 FT



DISCHARGE 550,000 CFS
HEADWATER EL 66.2
TAILWATER EL 61.4

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND
APRON EL -35.0; BAFFLE HEIGHT = 20 FT

VELOCITY DISTRIBUTION
AT THE END OF STILLING BASIN
TYPE 1 (ORIGINAL) STILLING BASIN APRON
LOOKING DOWNSTREAM
ALL GATES FULLY OPEN



LEGEND

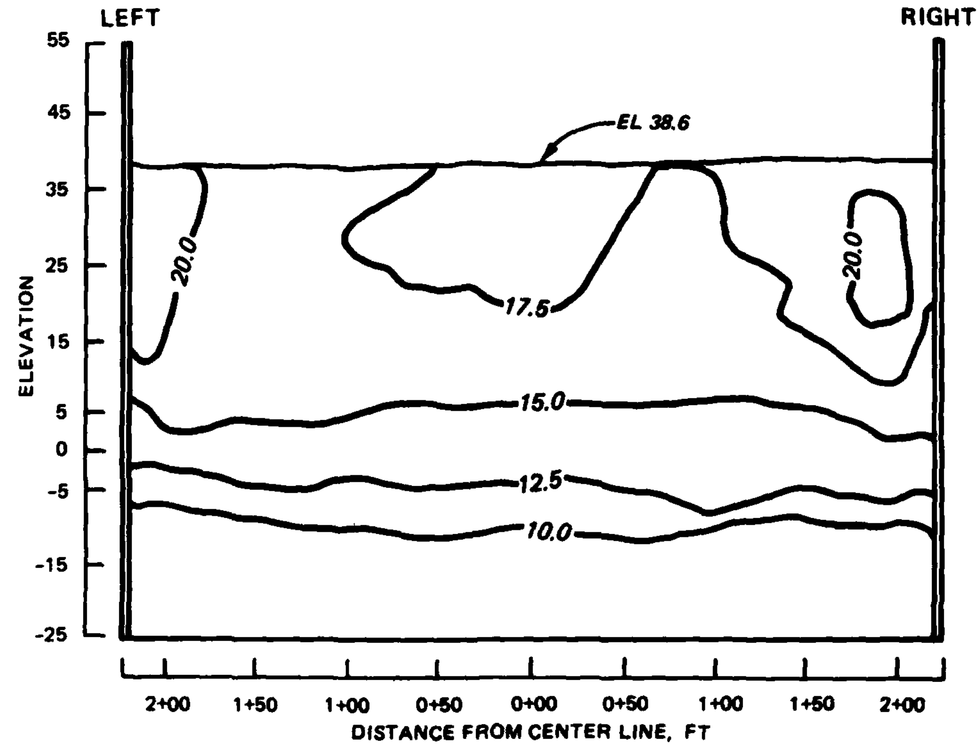
DOWNSTREAM (solid line)

UPSTREAM (dashed line)

DISCHARGE 90,000 CFS
HEADWATER EL 55.0
TAILWATER EL 24.2

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND
APRON EL -25.0; BAFFLE HEIGHT = 20 FT

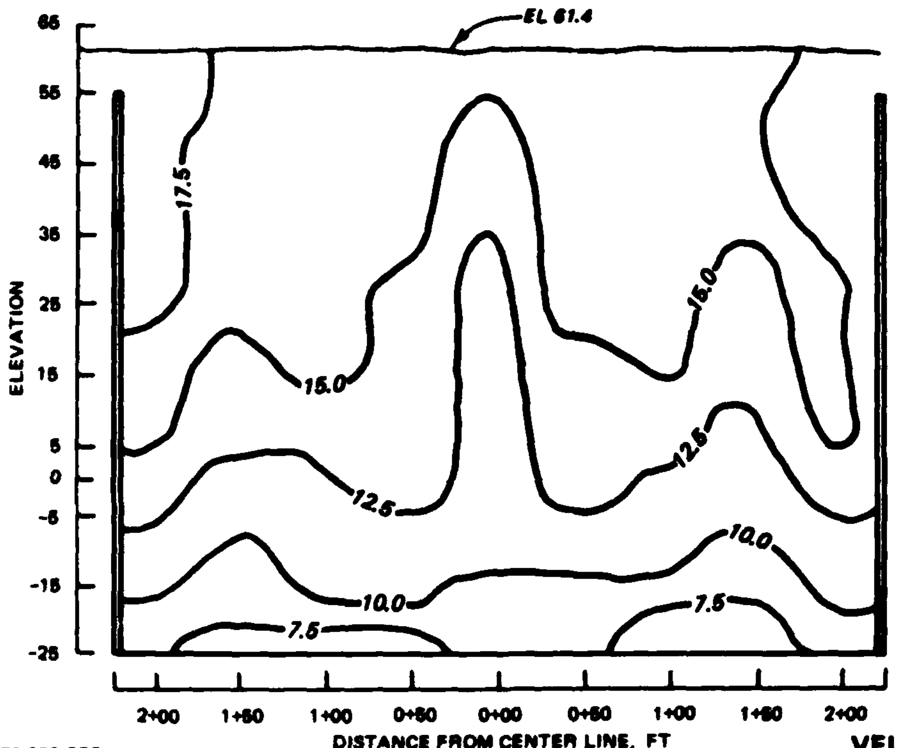
VELOCITY DISTRIBUTION
AT THE END OF STILLING BASIN
TYPE 2 (ORIGINAL) STILLING BASIN APRON
LOOKING DOWNSTREAM
ONE SIDE GATE FULLY OPEN



DISCHARGE	374,000 CFS
HEADWATER EL	52.0
TAILWATER EL	38.6

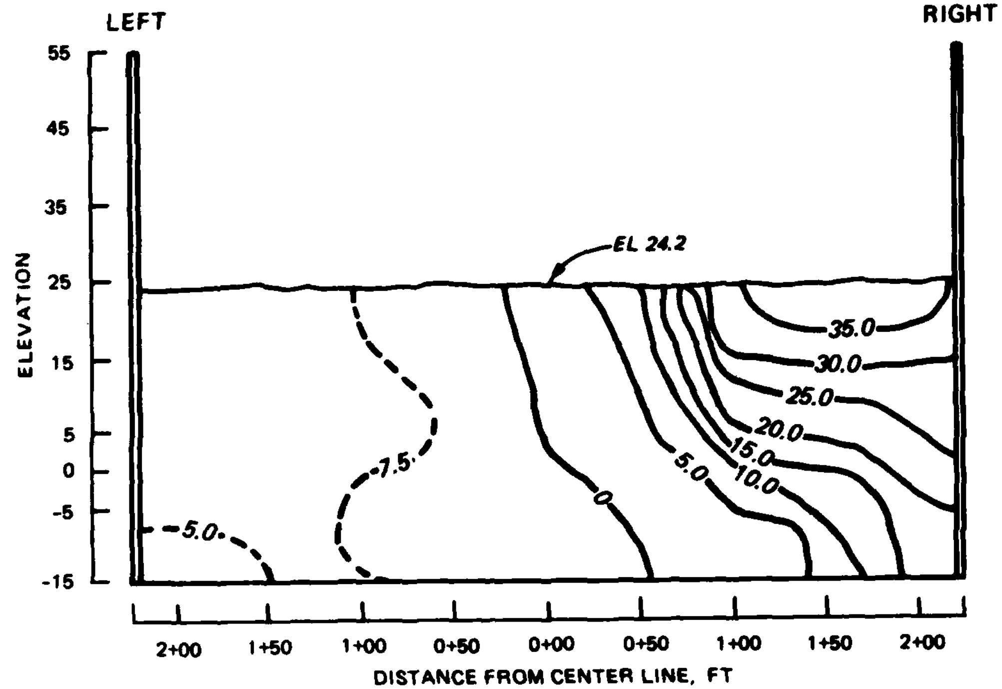
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND
APRON EL -25.0; BAFFLE HEIGHT = 20 FT

VELOCITY DISTRIBUTION
AT THE END OF STILLING BASIN
TYPE 2 (ORIGINAL) STILLING BASIN APRON
LOOKING DOWNSTREAM
G_o = 36.0 FT



DISCHARGE 550,000 CFS
HEADWATER EL 68.2
TAILWATER EL 61.4
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND
APRON EL -20.0; BAFFLE HEIGHT = 20 FT

VELOCITY DISTRIBUTION
AT THE END OF STILLING BASIN
TYPE 2 (ORIGINAL) STILLING BASIN APRON
LOOKING DOWNSTREAM
ALL GATES FULLY OPEN



DISCHARGE	90,000 CFS
HEADWATER EL	55.0
TAILWATER EL	24.2

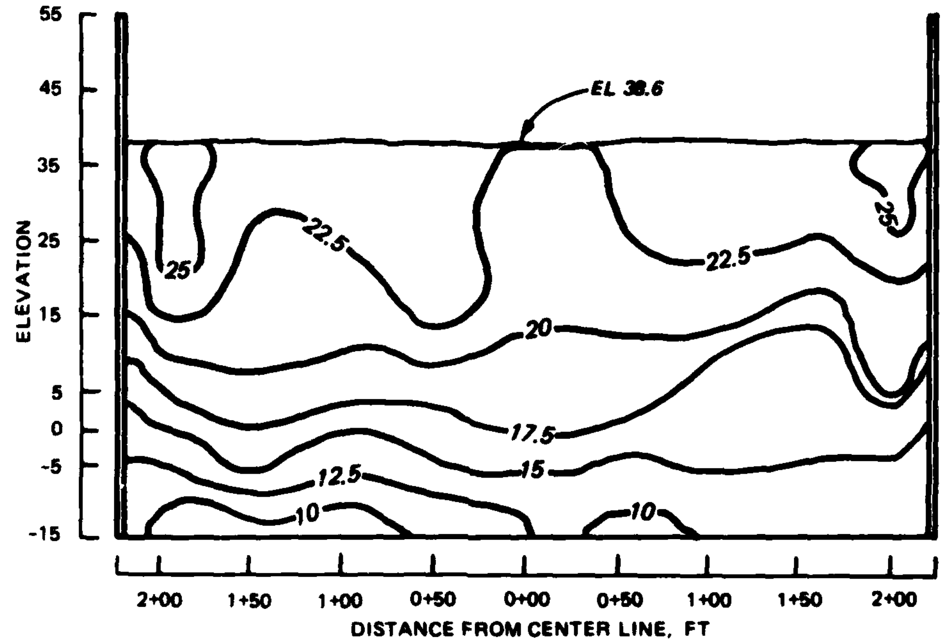
LEGEND

——— DOWNSTREAM

- - - - UPSTREAM

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND
APRON EL -15.0; BAFFLE HEIGHT = 20 FT

VELOCITY DISTRIBUTION
AT THE END OF STILLING BASIN
TYPE 3 (ORIGINAL) STILLING BASIN APRON
LOOKING DOWNSTREAM
ONE SIDE GATE FULLY OPEN



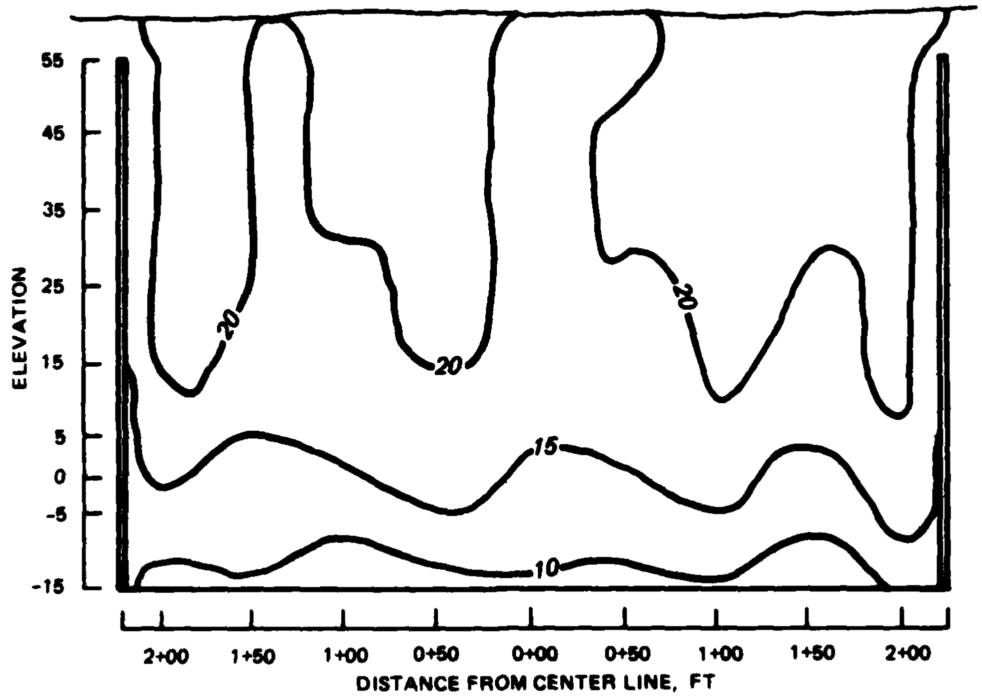
DISCHARGE	374,000 CFS
HEADWATER EL	52.0
TAILWATER EL	38.6

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND
APRON EL −15.0; BAFFLE HEIGHT = 20 FT

VELOCITY DISTRIBUTION AT THE END OF STILLING BASIN

TYPE 3 (ORIGINAL) STILLING BASIN APRON LOOKING DOWNSTREAM

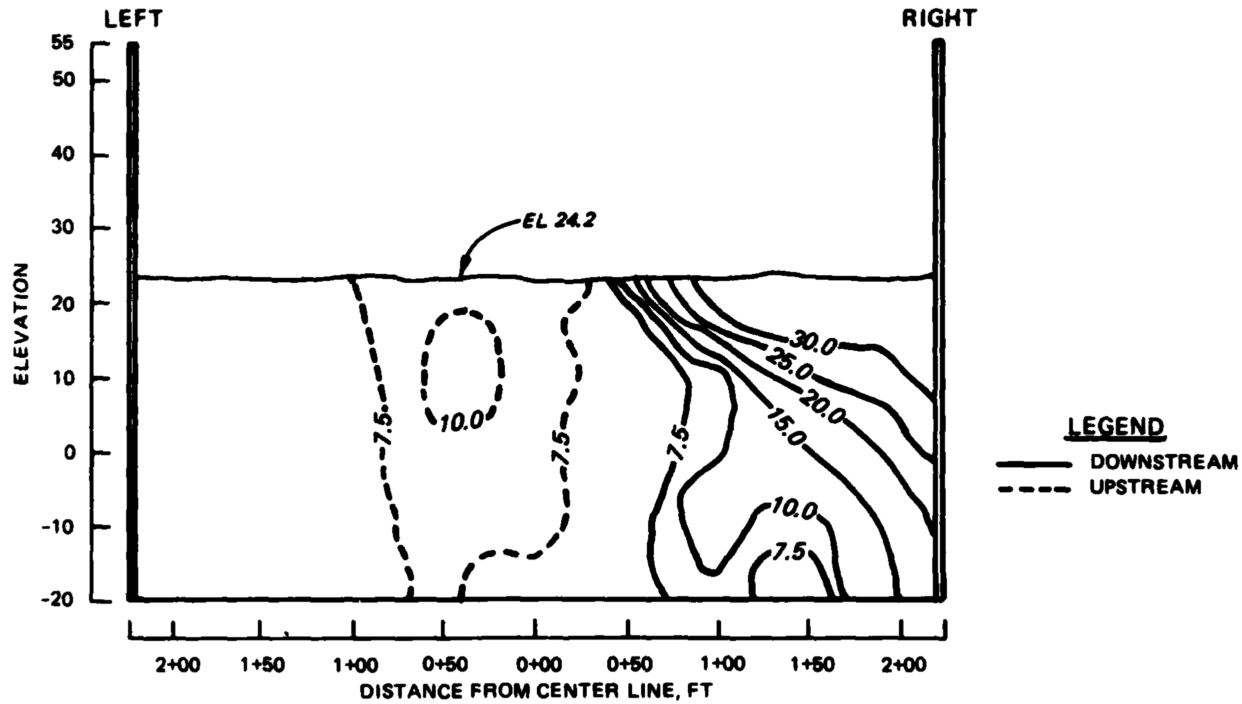
G_o = 36.0 FT



DISCHARGE	550,000 CFS
HEADWATER EL	66.2
TAILWATER EL	61.4

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND
APRON EL -15.0; BAFFLE HEIGHT = 20 FT

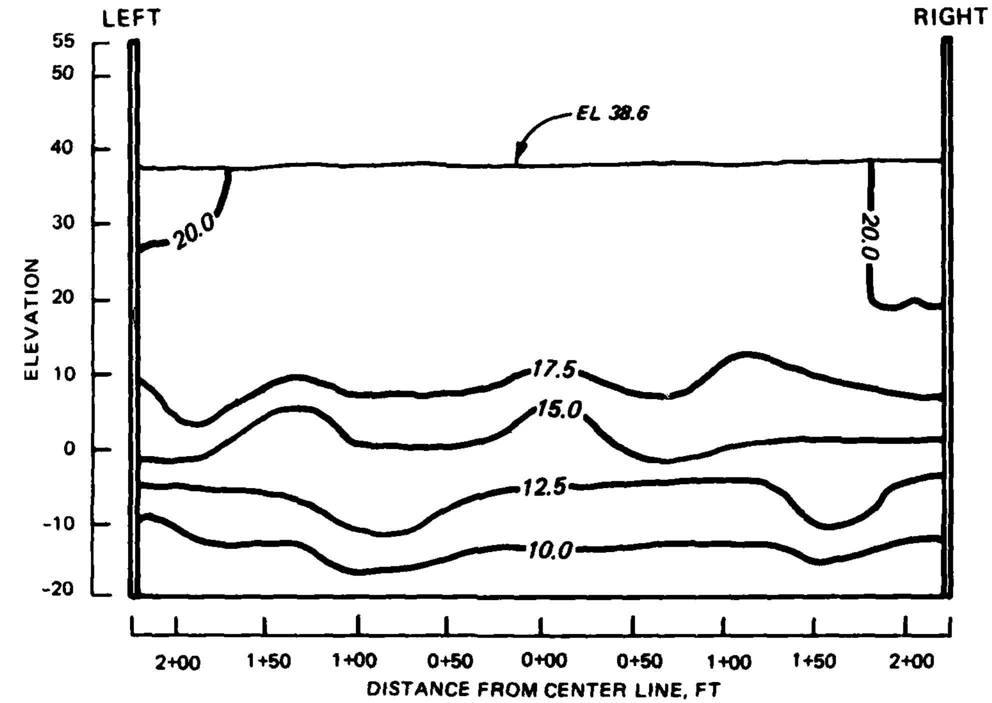
VELOCITY DISTRIBUTION
AT THE END OF STILLING BASIN
TYPE 3 (ORIGINAL) STILLING BASIN APRON
LOOKING DOWNSTREAM
ALL GATES FULLY OPEN



DISCHARGE	90,000 CFS
HEADWATER EL	55.0
TAILWATER EL	24.2

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND
APRON EL -20; BAFFLE HEIGHT = 20 FT

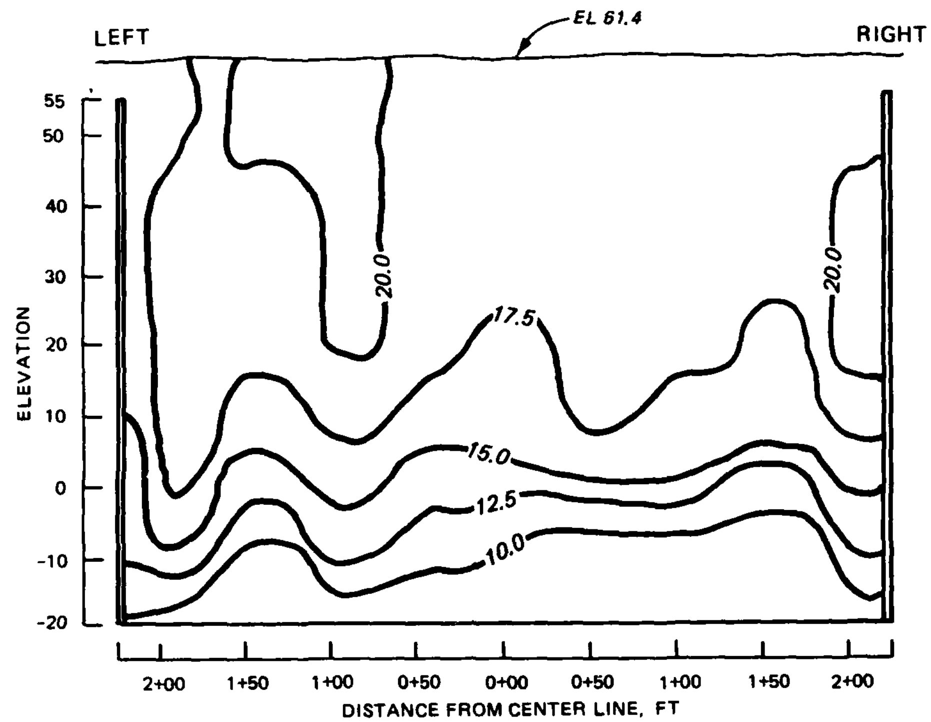
VELOCITY DISTRIBUTION
AT THE END OF STILLING BASIN
TYPE 4 (ORIGINAL) STILLING BASIN APRON
LOOKING DOWNSTREAM
ONE SIDE GATE FULLY OPEN



DISCHARGE 374,000 CFS
HEADWATER EL 52.0
TAILWATER EL 38.6

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND
APRON EL -20.0; BAFFLE HEIGHT = 20 FT

VELOCITY DISTRIBUTION
AT THE END OF STILLING BASIN
TYPE 4 (ORIGINAL) STILLING BASIN APRON
LOOKING DOWNSTREAM
G_o = 36.0 FT

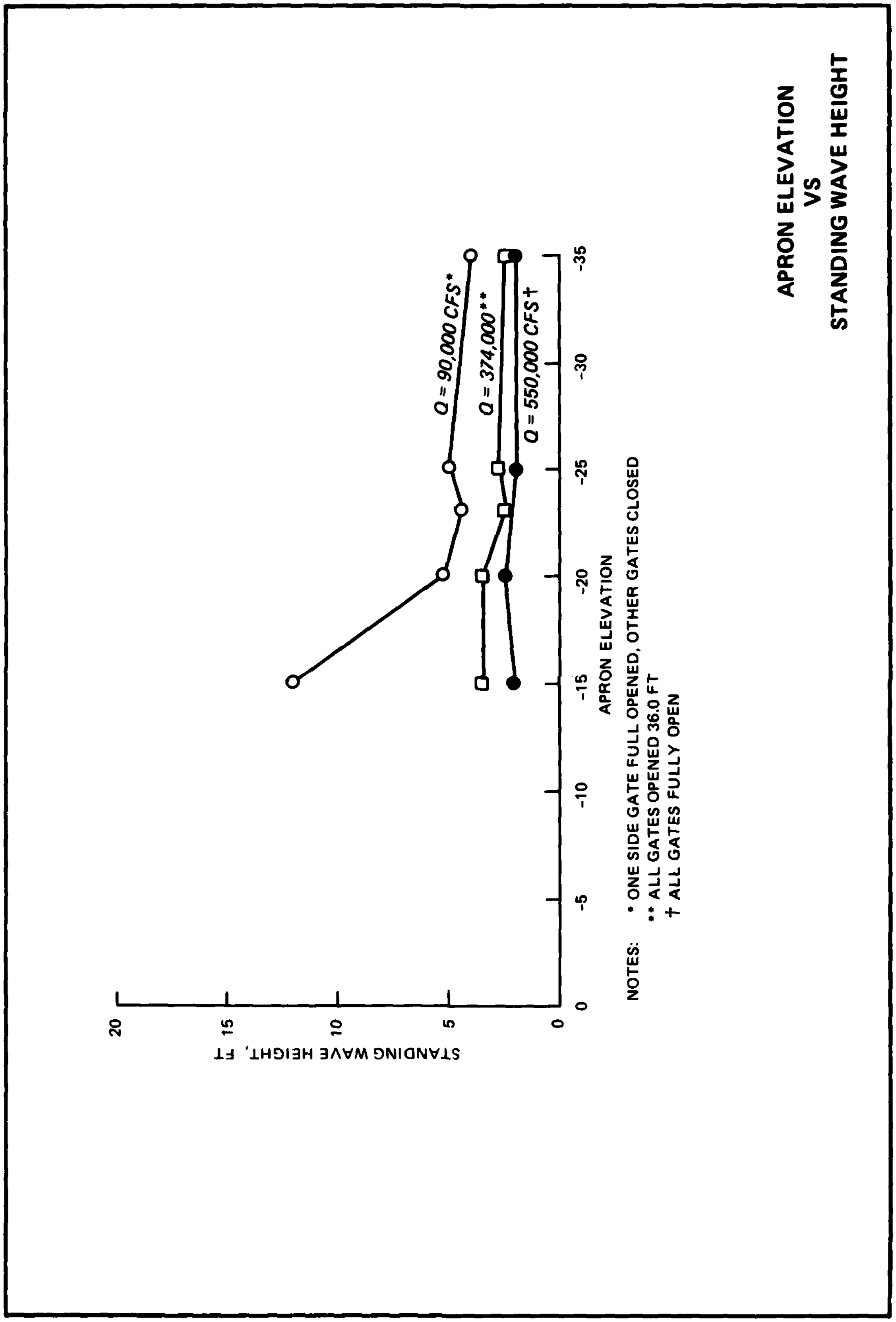


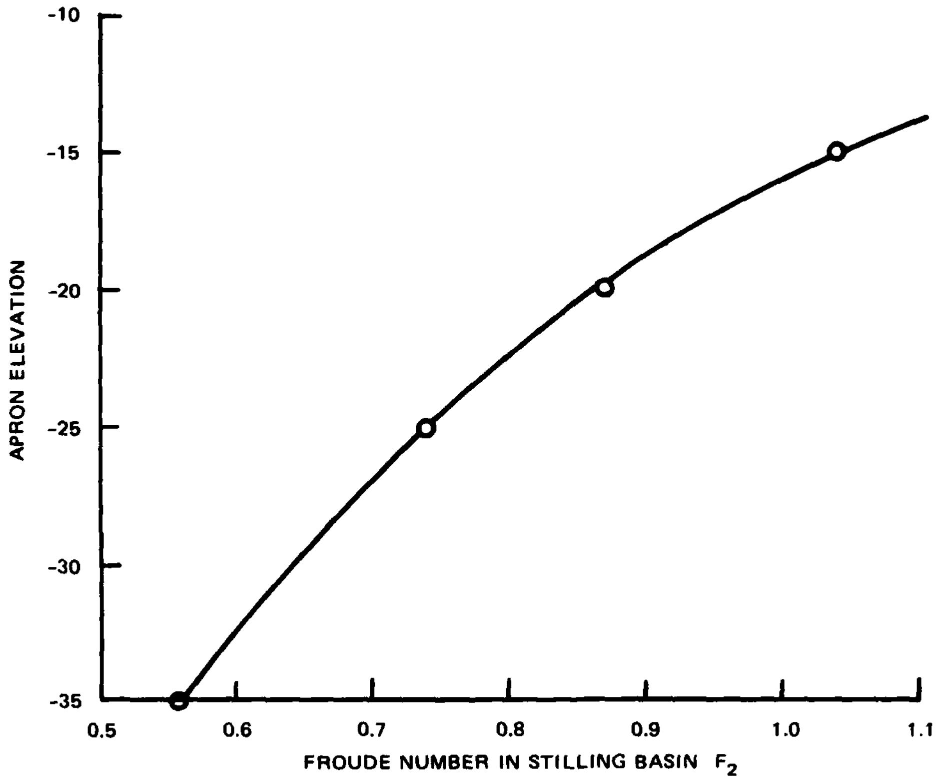
DISCHARGE 550,000 CFS
HEADWATER EL 66.2
TAILWATER EL 61.4

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND
APRON EL -20.0; BAFFLE HEIGHT = 20 FT

VELOCITY DISTRIBUTION AT THE END OF STILLING BASIN

TYPE 4 (ORIGINAL) STILLING BASIN APRON LOOKING DOWNSTREAM ALL GATES FULLY OPEN


APRON ELEVATION
VS
STANDING WAVE HEIGHT
STANDING WAVE HEIGHT, FT
20
15
10
5
0
0
-5
-10
-15
-20
-25
-30
-35
APRON ELEVATION
Q = 90,000 CFS*
Q = 374,000**
Q = 550,000 CFS†
NOTES: * ONE SIDE GATE FULL OPENED, OTHER GATES CLOSED
** ALL GATES OPENED 36.0 FT
† ALL GATES FULLY OPEN



$F_2 = \frac{V_2}{\sqrt{gD}}$

F_2 FROUDE NUMBER IN STILLING BASIN

V_2 AVERAGE VELOCITY IN STILLING BASIN ASSUME 62' WIDTH

g ACCELERATION DUE TO GRAVITY

D DEPTH OF FLOW IN STILLING BASIN

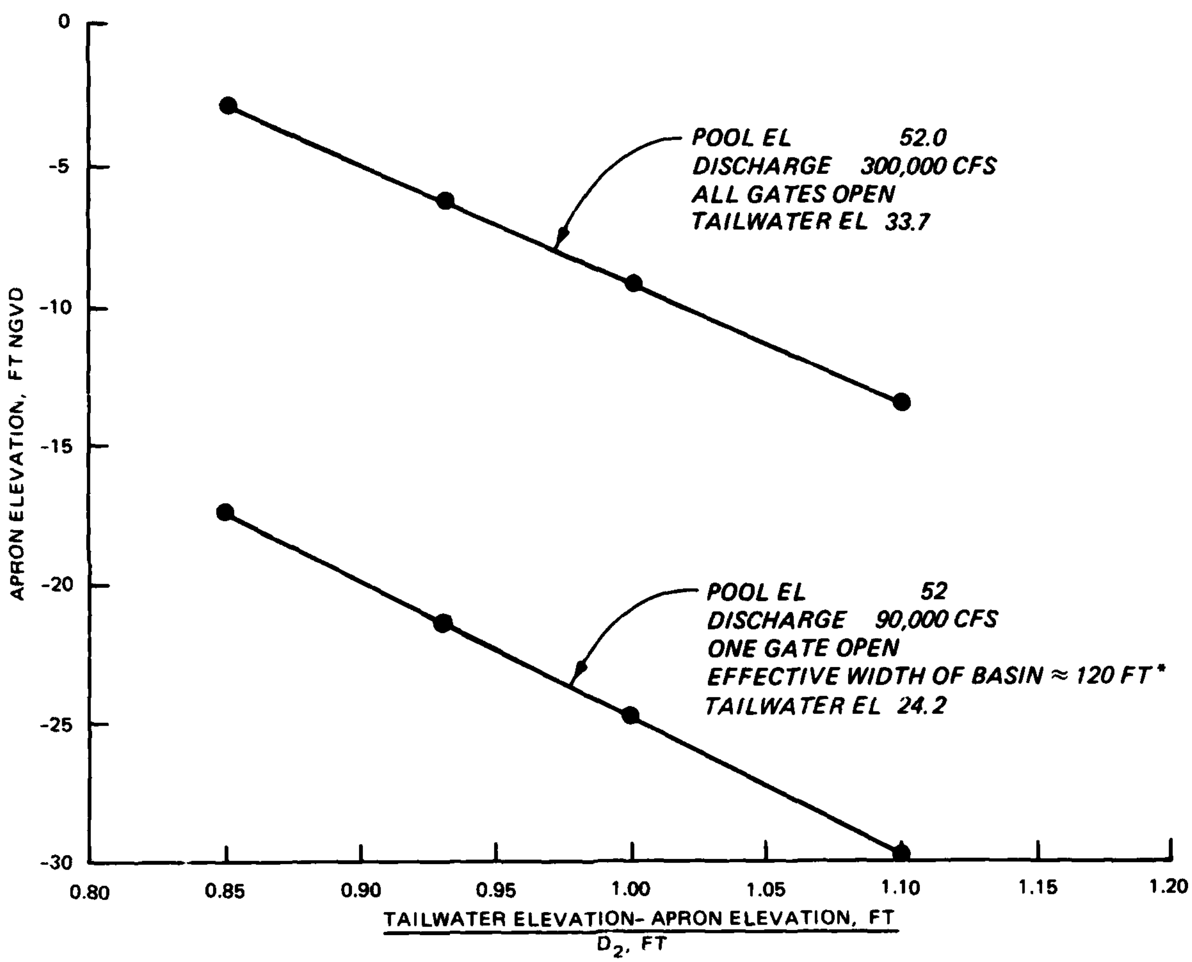
APRON ELEVATION VS FROUDE NUMBER

POOL EL 52.0

TAILWATER EL 24.2

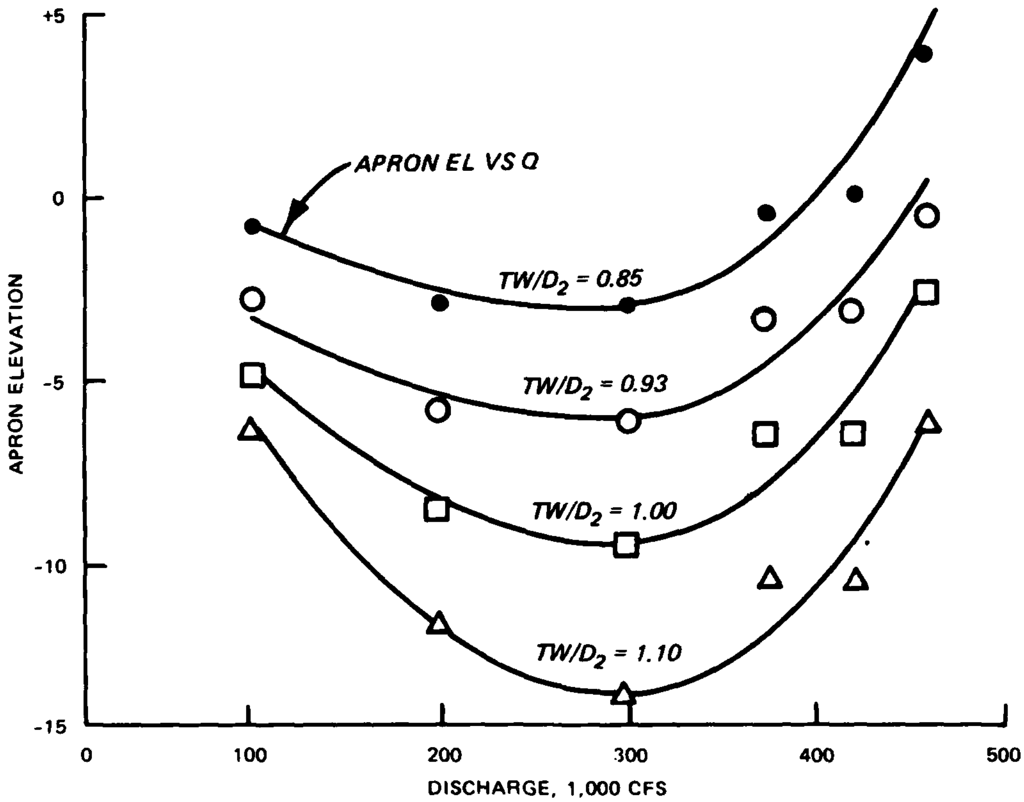
DISCHARGE 90,000 CFS

ONE GATE FULLY OPEN

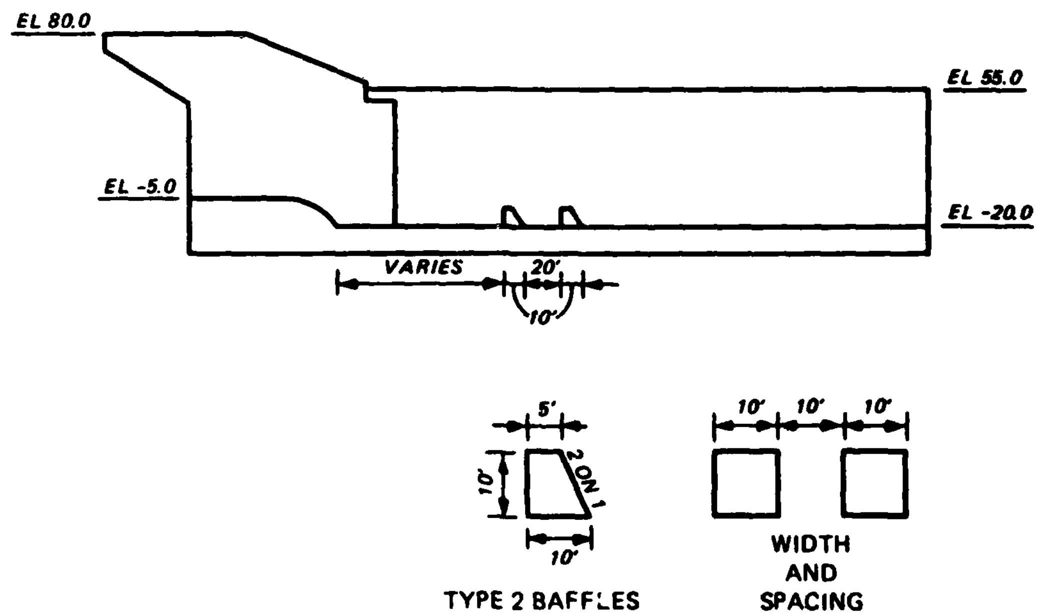


*NOTE: APPROXIMATE EFFECTIVE WIDTH OF STILLING BASIN INDICATED BY VELOCITY MEASUREMENTS OVER THE END SILL

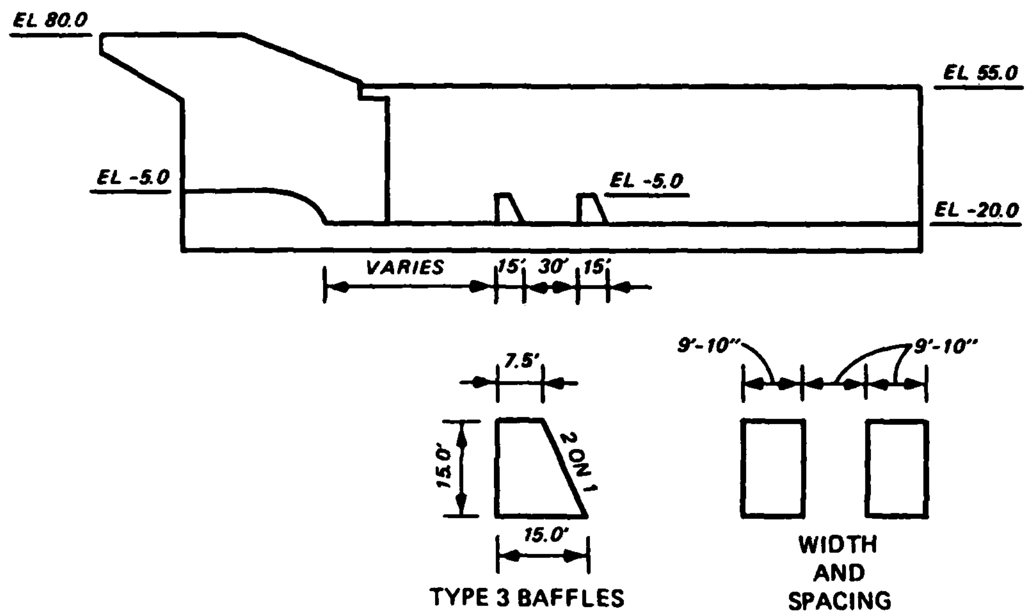
APRON ELEVATION VERSUS TW/D_2
MINIMUM ANTICIPATED TAILWATER ELEVATION



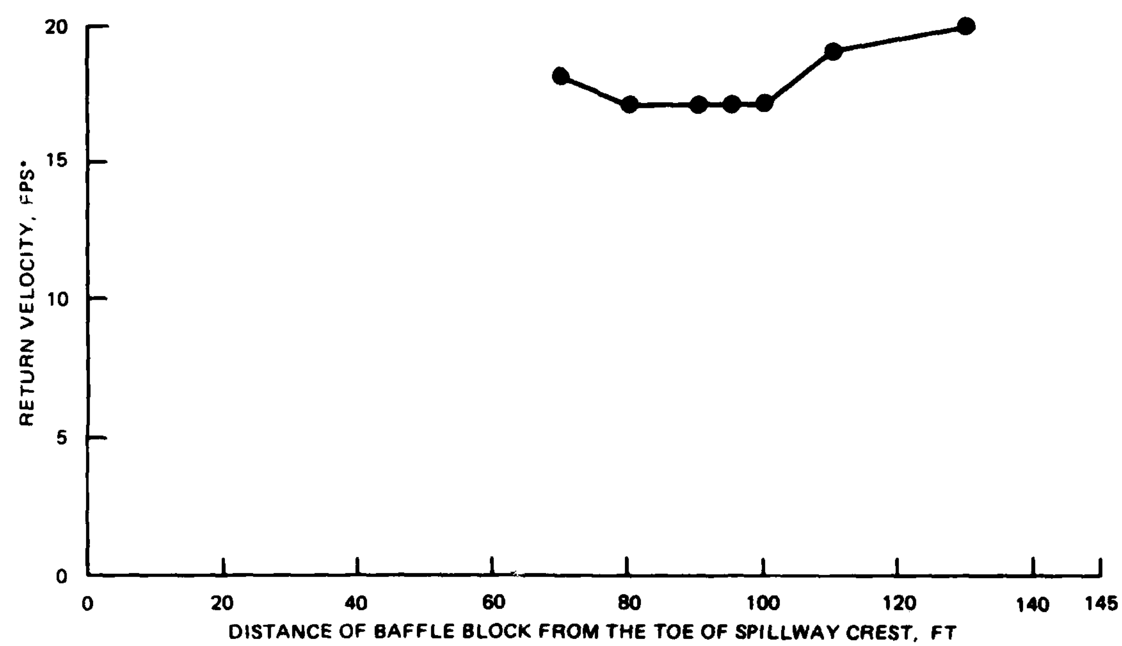
APRON ELEVATION VS DISCHARGE
MINIMUM ANTICIPATED TAILWATER ELEVATIONS



TYPE 4 APRON EL -20.0
TYPE 2 BAFFLE BLOCKS 10.0 FT HIGH



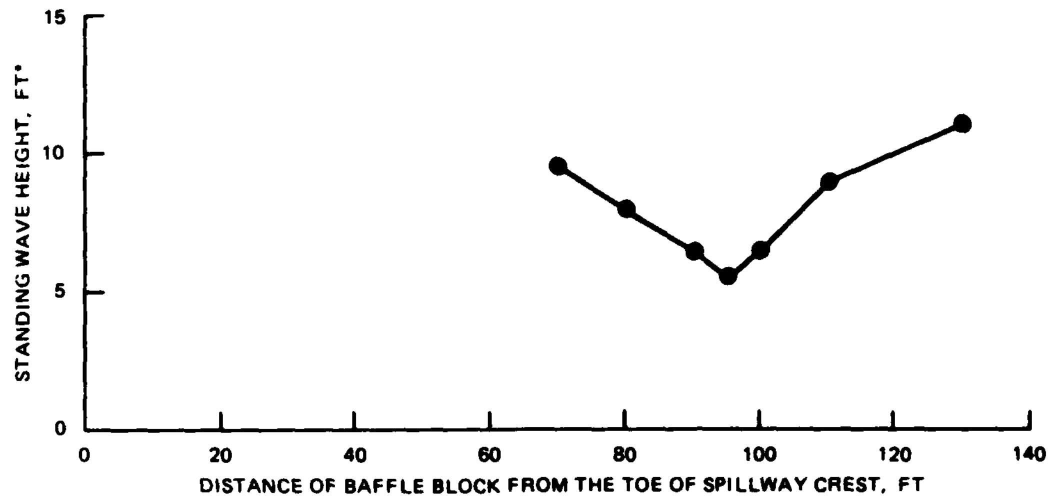
TYPE 4 APRON EL -20.0
TYPE 3 BAFFLE BLOCKS 15.0 FT HIGH



Q = 90,000 CFS WITH ONE GATE FULLY OPEN
POOL EL 54.0
TAILWATER EL 24.2
STILLING BASIN EL -20.0
TYPE 3 BAFFLE BLOCKS (HEIGHT 15 FT)

*NOTE: MEASURED ALONG THE BANK APPROXIMATELY 900 FT FROM THE CREST OF SPILLWAY

**BAFFLE BLOCK LOCATION
VS
RETURN VELOCITY**



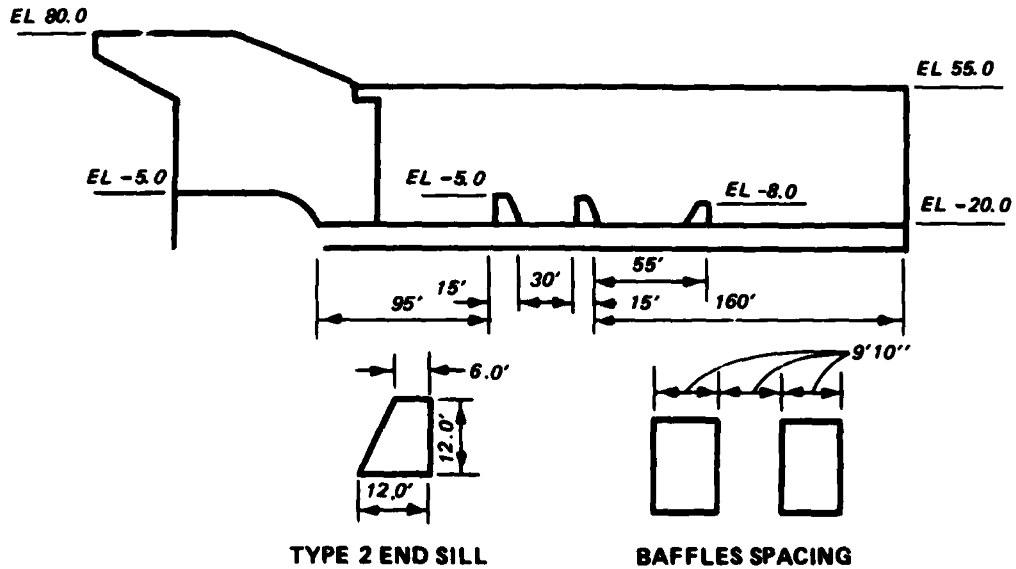
Q = 90,000 CFS WITH ONE GATE FULLY OPEN

POOL EL	54.0
TAILWATER EL	24.2
STILLING BASIN EL	-20.0

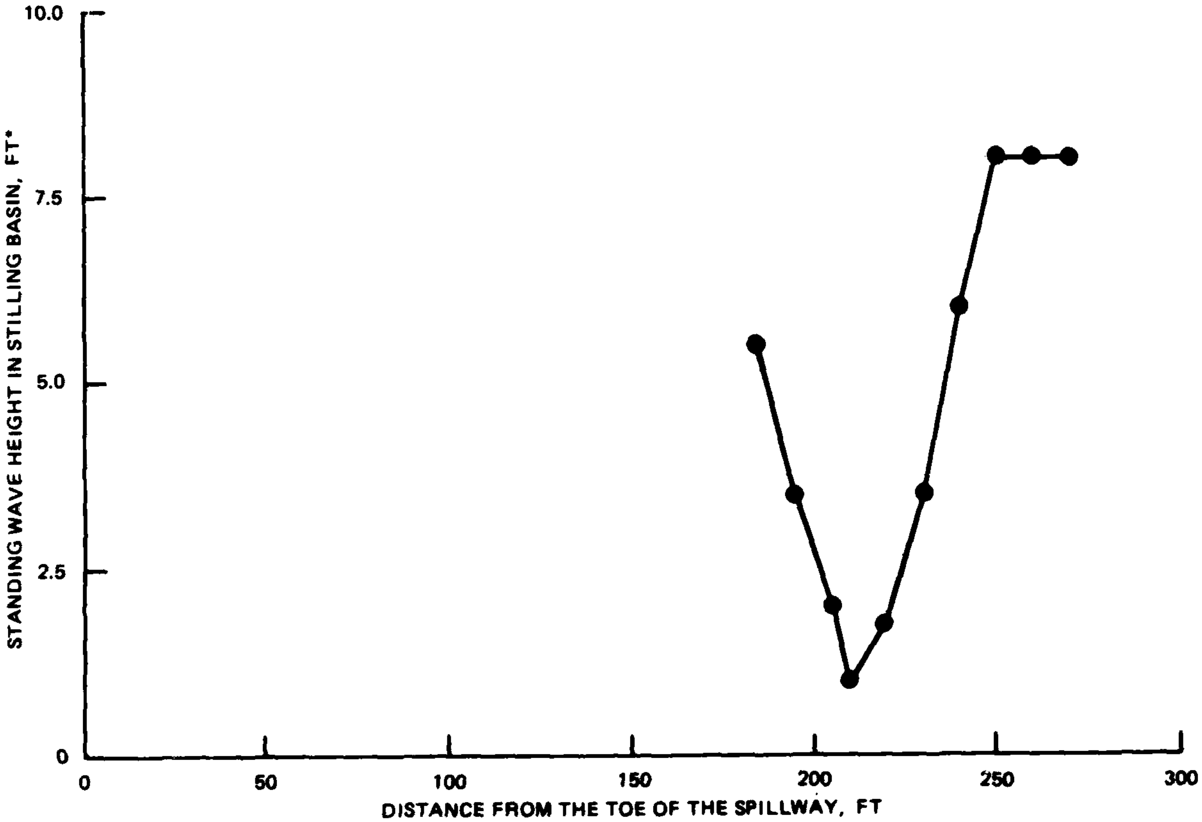
TYPE 3 BAFFLE BLOCK (HEIGHT 15 FT)

*NOTE: MAXIMUM WAVE HEIGHT IN STILLING BASIN

BAFFLE BLOCK LOCATION
VS
STANDING WAVE HEIGHT



TYPE 4 APRON	EL -20.0
TYPE 3 BAFFLE BLOCKS	15 FT HIGH
TYPE 2 END SILL	12 FT HIGH



Q = 90,000 CFS WITH ONE GATE FULLY OPEN

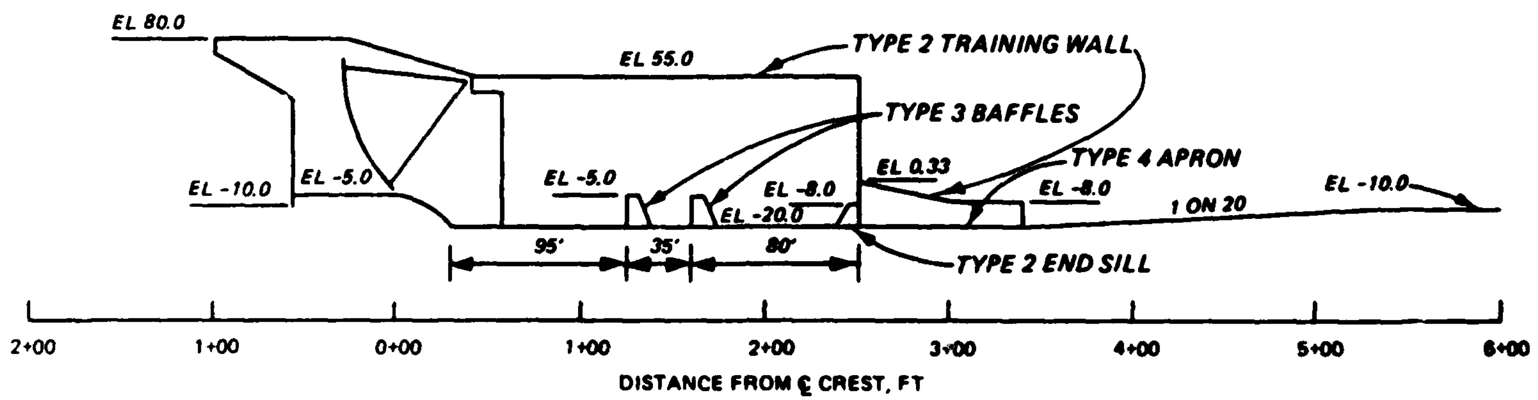
POOL EL 54.0

TAILWATER EL 24.2

* MEASURED ALONG THE TRAINING WALL WHERE THE FIRST WAVE CYCLE OCCURRED

END SILL LOCATION VS STANDING WAVE HEIGHT

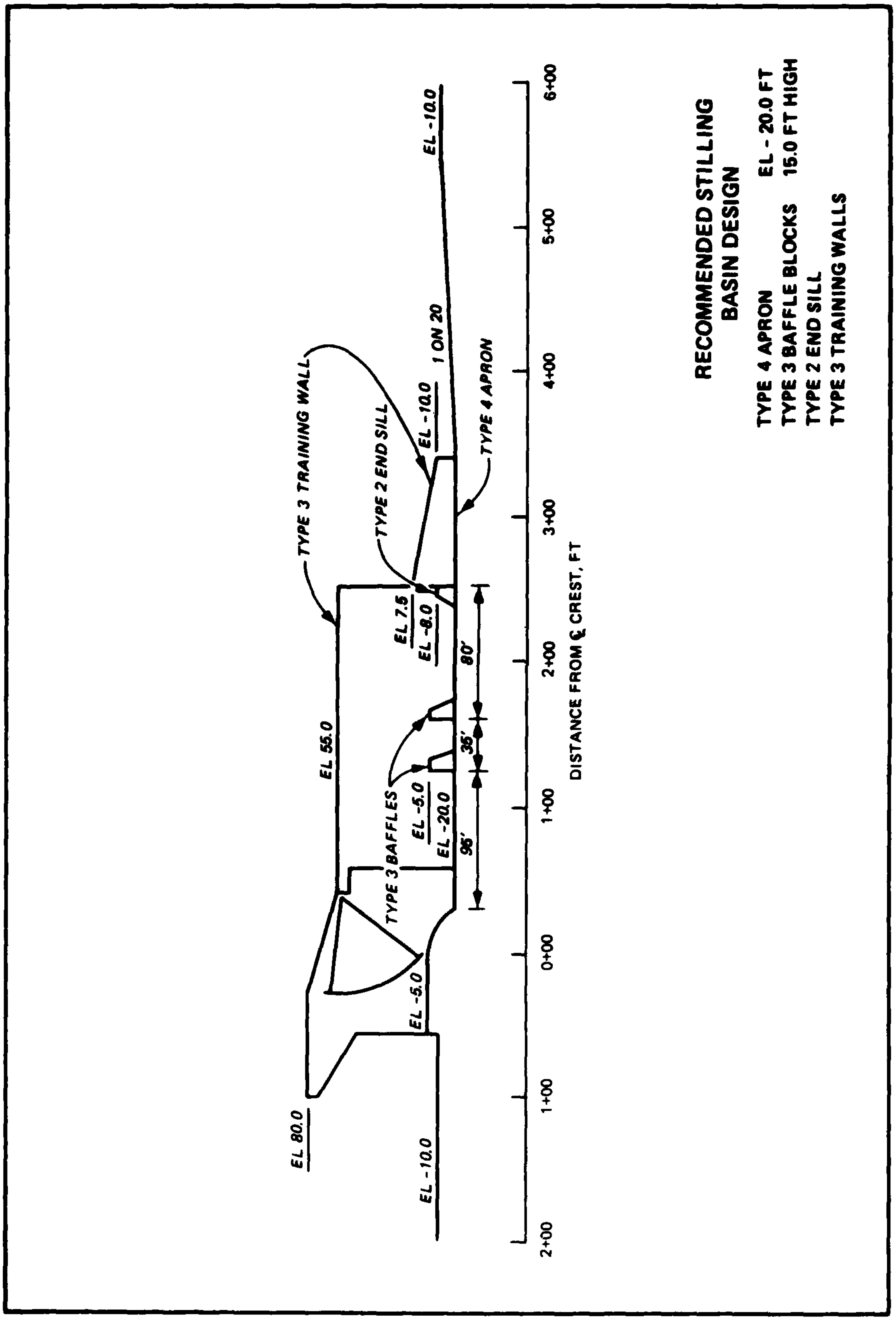
TYPE 4 APRON	EL - 20.0 FT
TYPE 3 BAFFLE BLOCKS	15.0 FT HIGH
TYPE 2 END SILL	12.0 FT HIGH

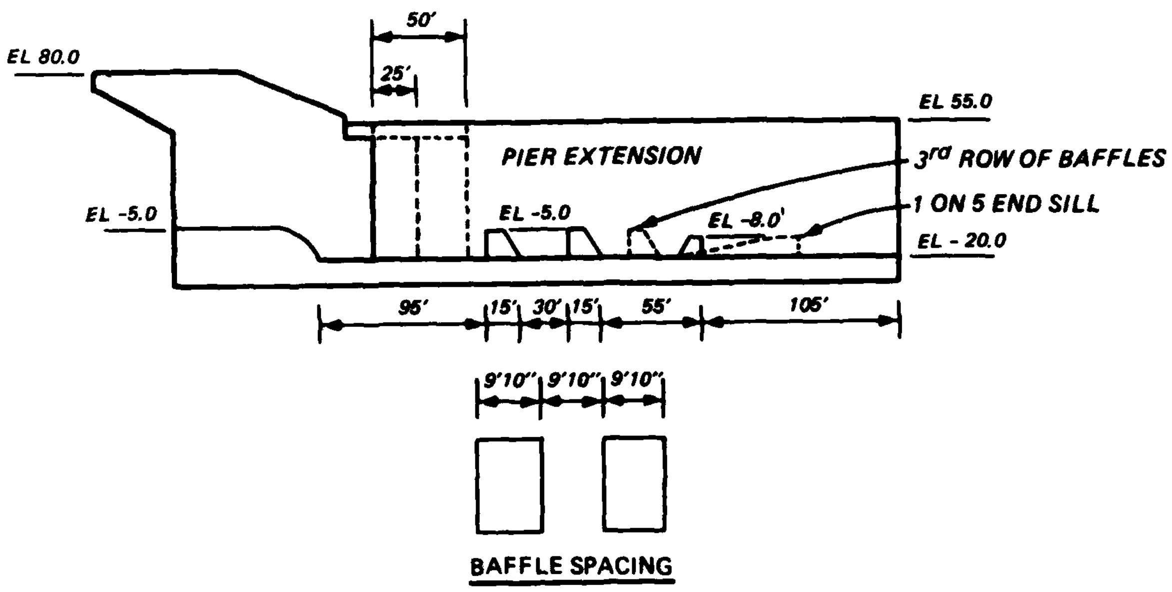


PROFILE

RECOMMENDED STILLING BASIN DESIGN

TYPE 4 APRON	EL -20.0 FT
TYPE 3 BAFFLE BLOCKS	15.0 FT HIGH
TYPE 2 END SILL	
TYPE 2 TRAINING WALLS	

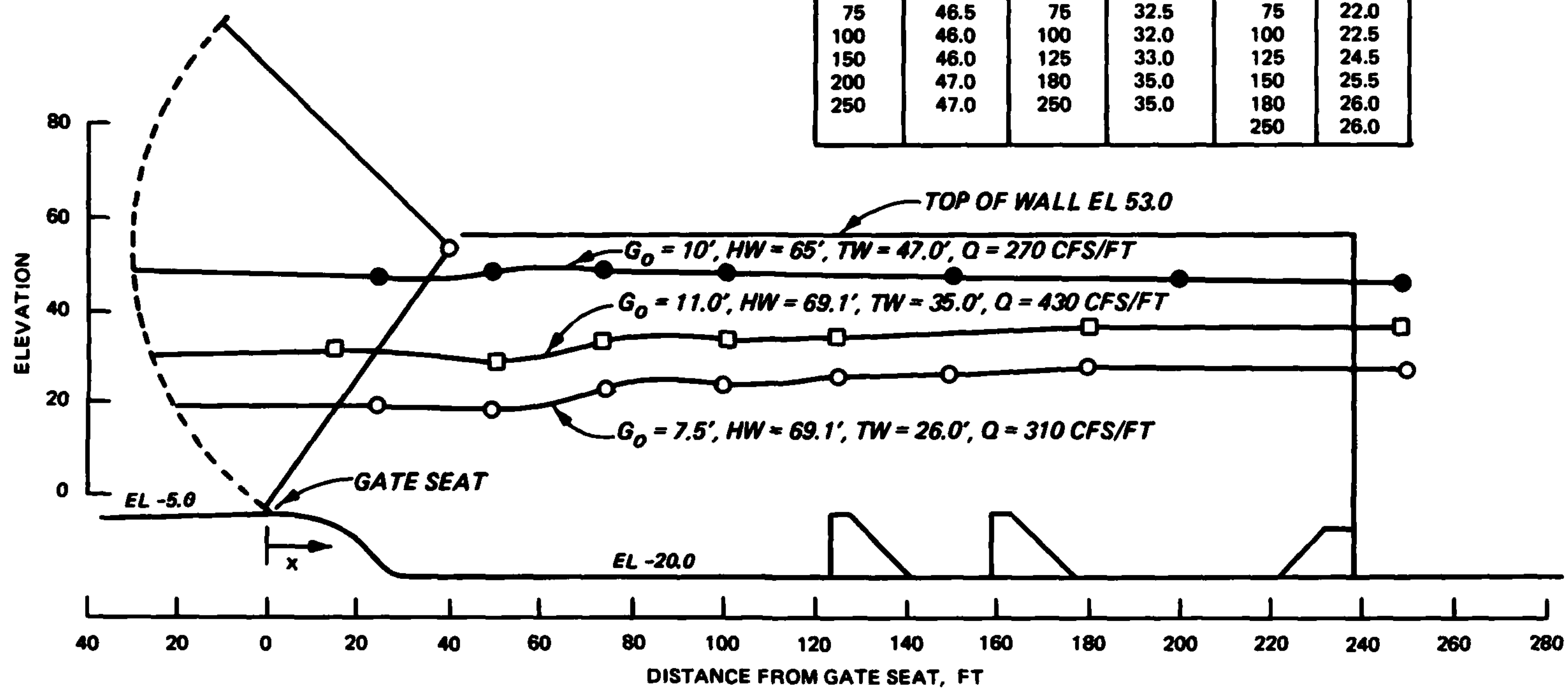

EL 80.0
EL -10.0
EL -5.0
EL 55.0
TYPE 3 BAFFLES
EL -5.0
EL -20.0
96'
36'
80'
EL 7.5
EL -8.0
TYPE 3 TRAINING WALL
TYPE 2 END SILL
EL -10.0
1 ON 20
TYPE 4 APRON
EL -10.0
1+00
0+00
1+00
2+00
3+00
4+00
5+00
6+00
DISTANCE FROM ℄ CREST, FT
RECOMMENDED STILLING BASIN DESIGN
TYPE 4 APRON EL - 20.0 FT
TYPE 3 BAFFLE BLOCKS 15.0 FT HIGH
TYPE 2 END SILL
TYPE 3 TRAINING WALLS



ADDITIONAL MODIFICATIONS
PIER EXTENSIONS
IV ON 5H END SILL
THIRD ROW OF TYPE 3 BAFFLE BLOCKS

BASIC DATA

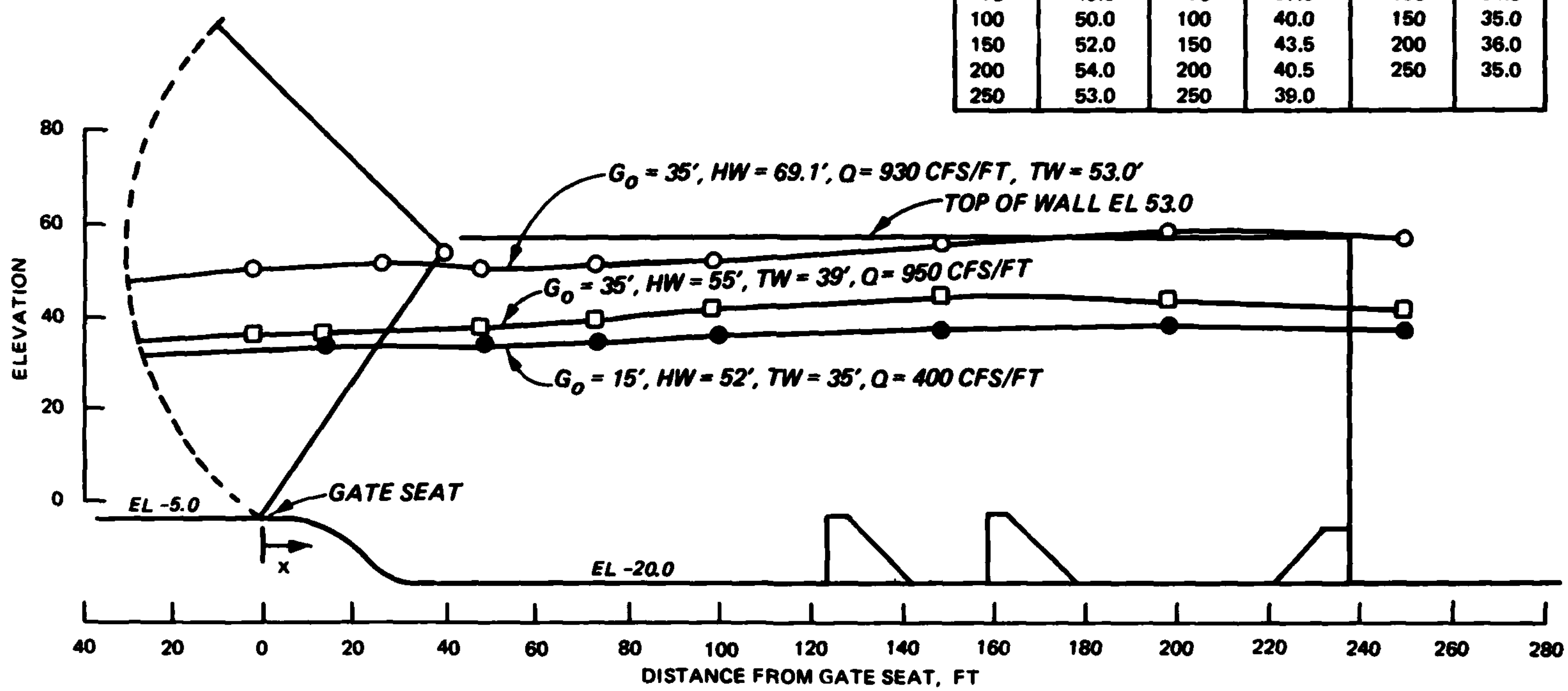
●		□		○	
X	EL	X	EL	X	EL
25	44.0	15	27.0	25	17.5
50	46.0	50	27.5	50	16.5
75	46.5	75	32.5	75	22.0
100	46.0	100	32.0	100	22.5
150	46.0	125	33.0	125	24.5
200	47.0	180	35.0	150	25.5
250	47.0	250	35.0	180	26.0
				250	26.0



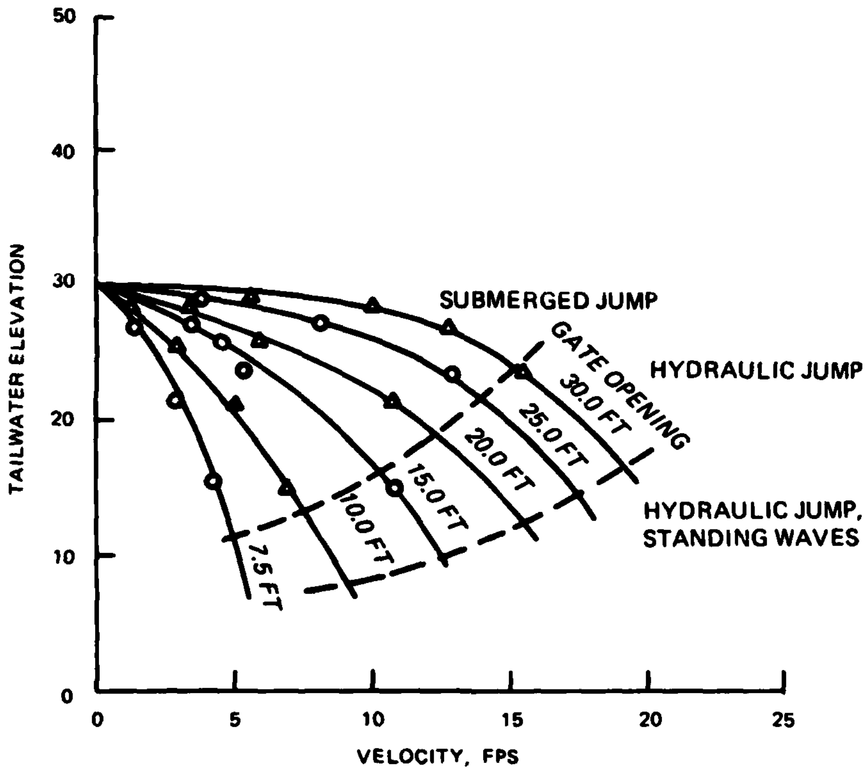
WATER-SURFACE PROFILES
RECOMMENDED STILLING BASIN
G_o = 7.5, 10, AND 11 FT

BASIC DATA

○ X	○ EL	□ X	□ EL	● X	● EL
0	47.5	0	33.5	15	29.0
25	48.0	15	33.0	50	31.5
50	48.0	50	34.0	75	33.5
75	49.0	75	37.5	100	34.0
100	50.0	100	40.0	150	35.0
150	52.0	150	43.5	200	36.0
200	54.0	200	40.5	250	35.0
250	53.0	250	39.0		



WATER-SURFACE PROFILES
RECOMMENDED STILLING BASIN
G_o = 15 AND 35 FT

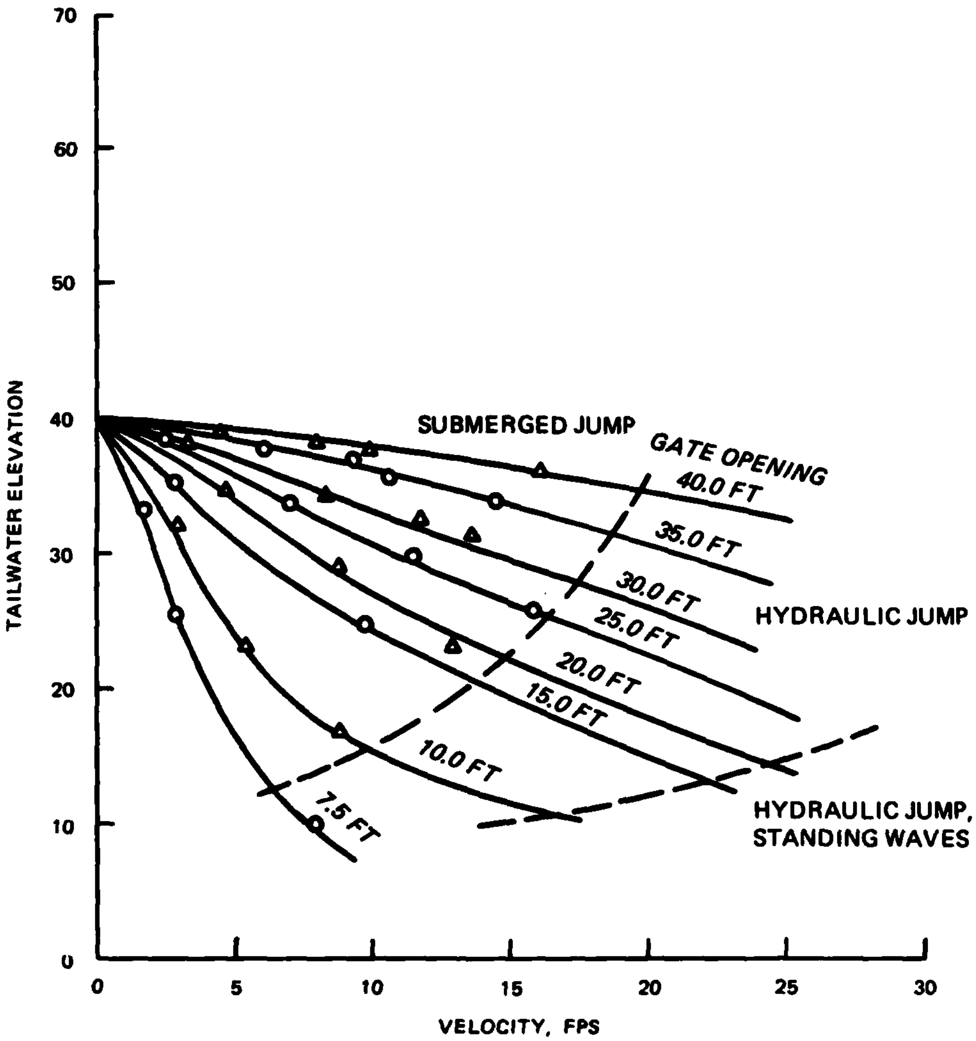


NOTE: VELOCITIES MEASURED 10 FT ABOVE THE EXIT CHANNEL BOTTOM AT THE END OF STILLING BASIN

RECOMMENDED STILLING BASIN DESIGN

STILLING BASIN PERFORMANCE FOR CONTROLLED FLOW

POOL EL 30.0

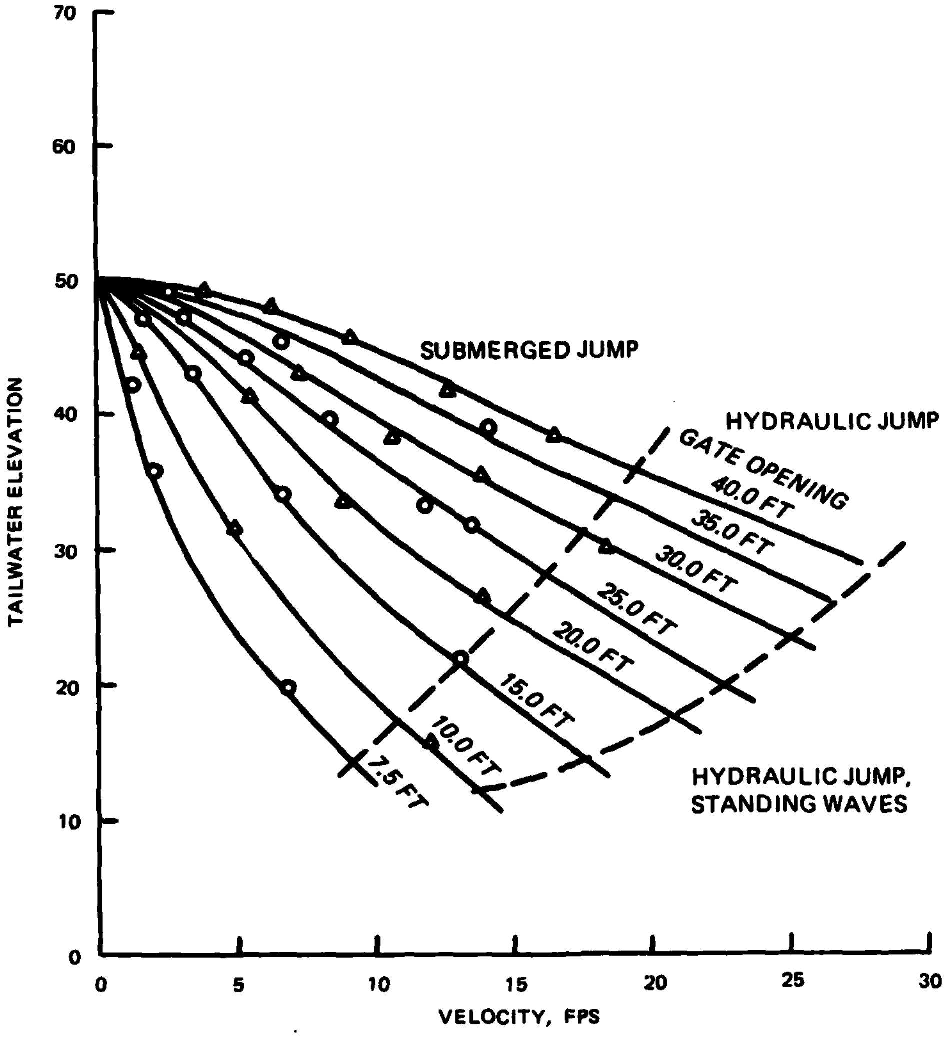


NOTE: VELOCITIES MEASURED 10 FT ABOVE THE EXIT CHANNEL BOTTOM AT THE END OF STILLING BASIN

RECOMMENDED STILLING BASIN DESIGN

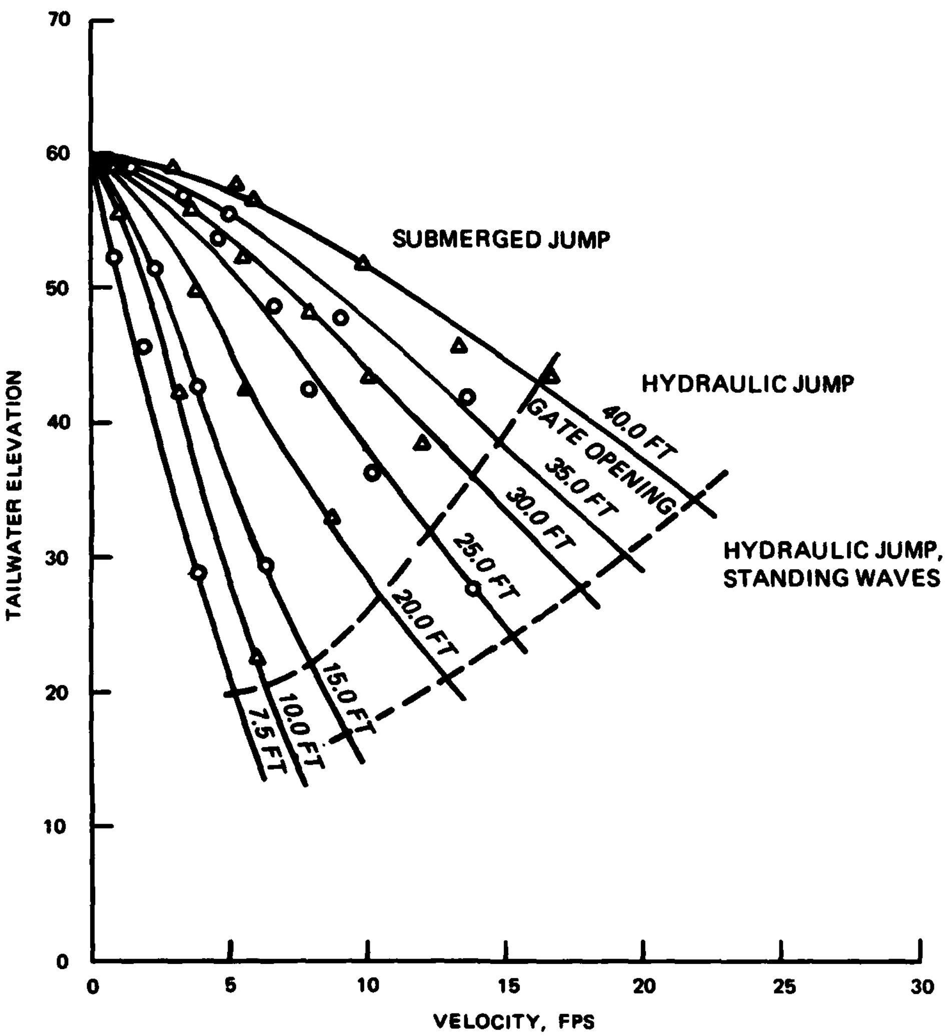
STILLING BASIN PERFORMANCE FOR CONTROLLED FLOW

POOL EL 40.0



NOTE: VELOCITIES MEASURED 10 FT ABOVE THE EXIT CHANNEL BOTTOM AT THE END OF STILLING BASIN

RECOMMENDED STILLING BASIN DESIGN
STILLING BASIN PERFORMANCE FOR CONTROLLED FLOW
POOL EL 50.0



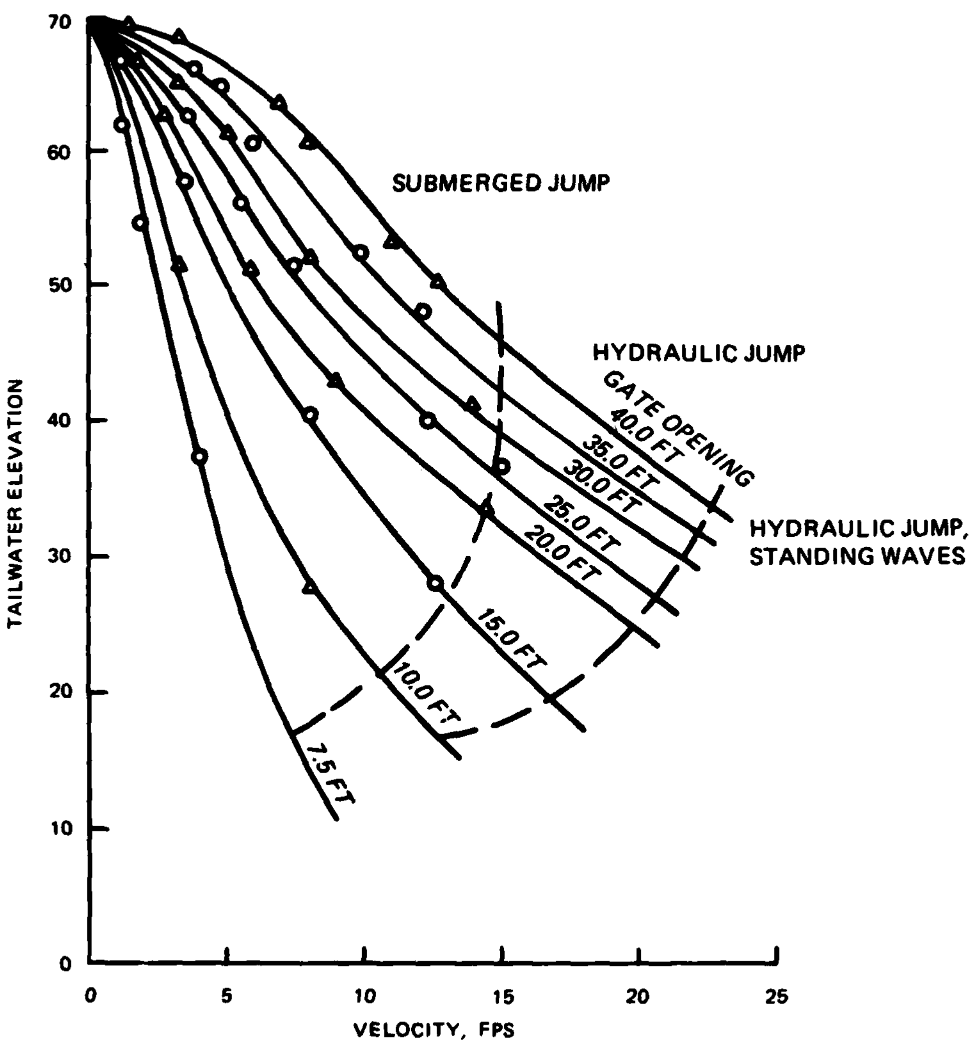
NOTE: VELOCITIES MEASURED 10 FT ABOVE THE EXIT CHANNEL BOTTOM AT THE END OF STILLING BASIN

RECOMMENDED STILLING BASIN DESIGN

STILLING BASIN PERFORMANCE FOR CONTROLLED FLOW

POOL ELEVATION 60.0

POOL EL 60.0

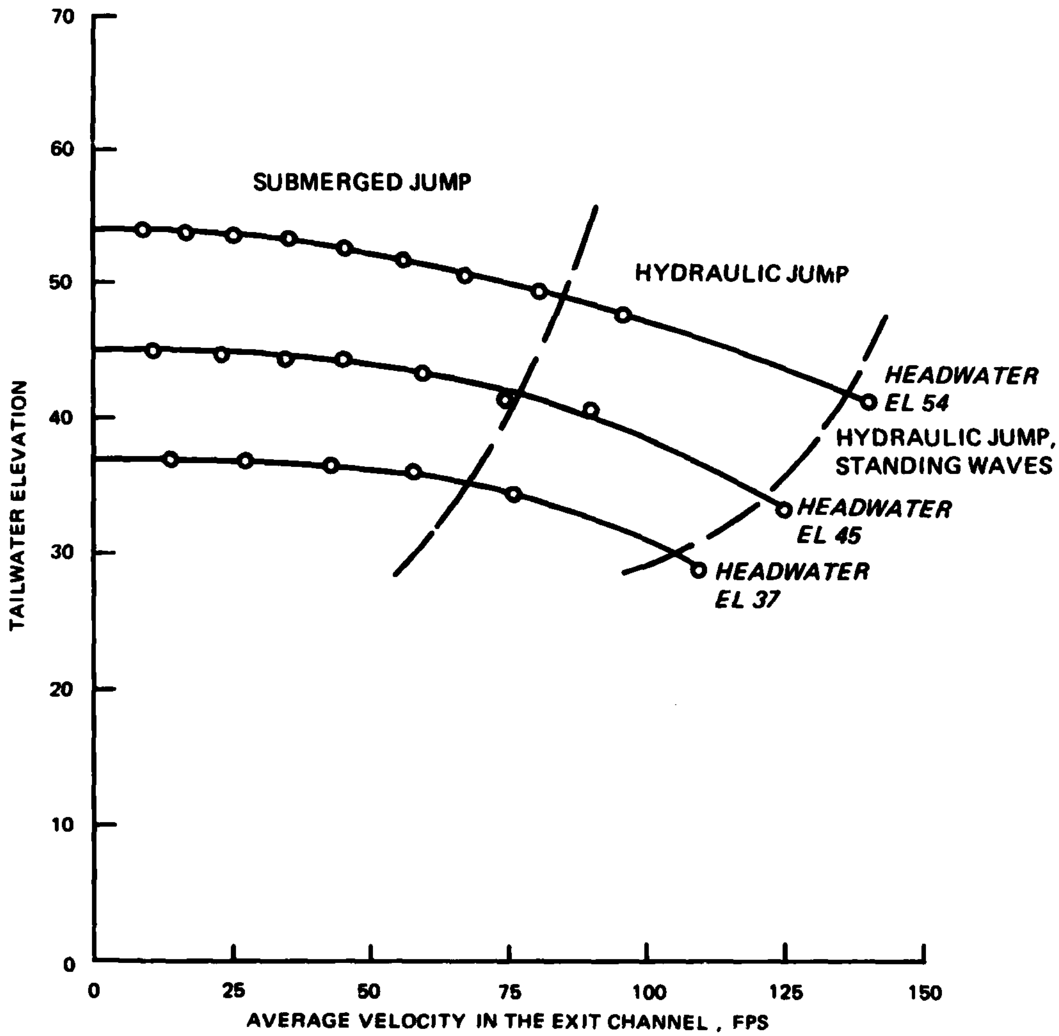


NOTE: VELOCITIES MEASURED 10 FT ABOVE THE EXIT CHANNEL BOTTOM AT THE END OF STILLING BASIN

RECOMMENDED STILLING BASIN DESIGN

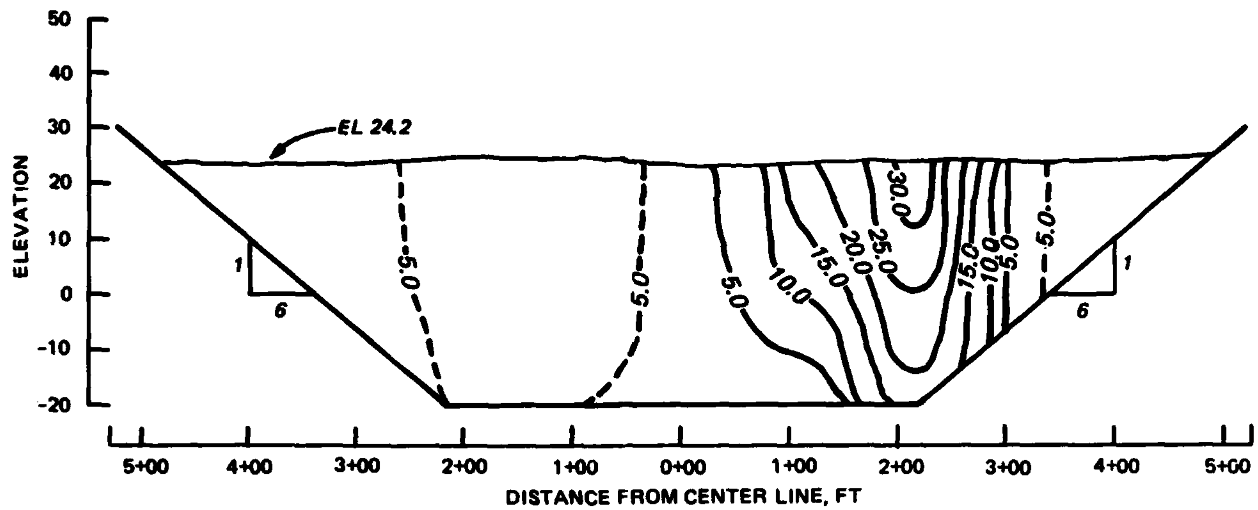
STILLING BASIN PERFORMANCE FOR CONTROLLED FLOW

POOL EL 70.0



RECOMMENDED STILLING BASIN DESIGN

STILLING BASIN PERFORMANCE FOR UNCONTROLLED FLOW



LEGEND

DOWNSTREAM

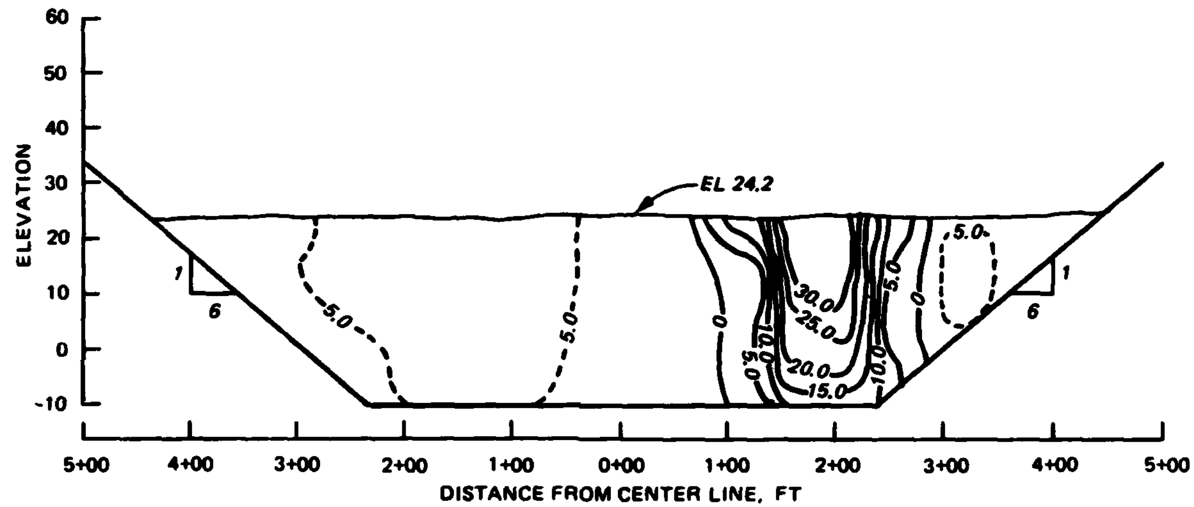
UPSTREAM

DISCHARGE 90,000 CFS
HEADWATER EL 55.0
TAILWATER EL 24.2

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND

VELOCITY DISTRIBUTION
105 FT DOWNSTREAM FROM END SILL

RECOMMENDED DESIGN
LOOKING DOWNSTREAM
G_o = END BAY ON RIGHT SIDE FULL OPEN

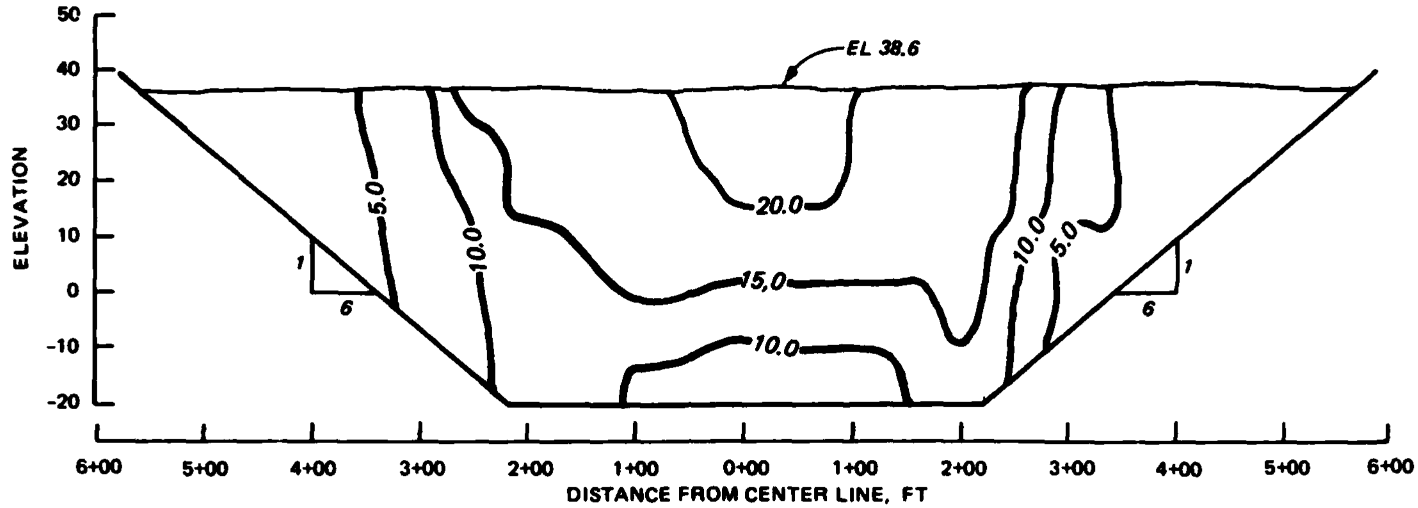


DISCHARGE 90,000 CFS
HEADWATER EL 55.0
TAILWATER EL 24.2

LEGEND
DOWNSTREAM
UPSTREAM

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND

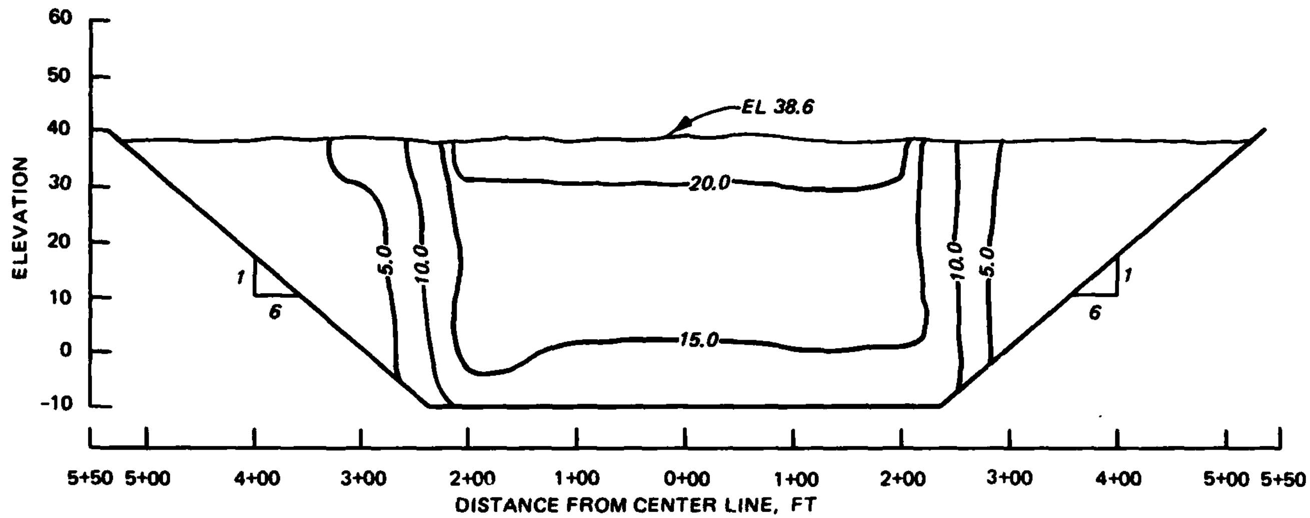
VELOCITY DISTRIBUTION
305 FT DOWNSTREAM FROM END SILL
RECOMMENDED DESIGN
LOOKING DOWNSTREAM
G_o = END BAY ON RIGHT SIDE FULL OPEN



DISCHARGE 374,000 CFS
HEADWATER EL 52.0
TAILWATER EL 38.6

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND

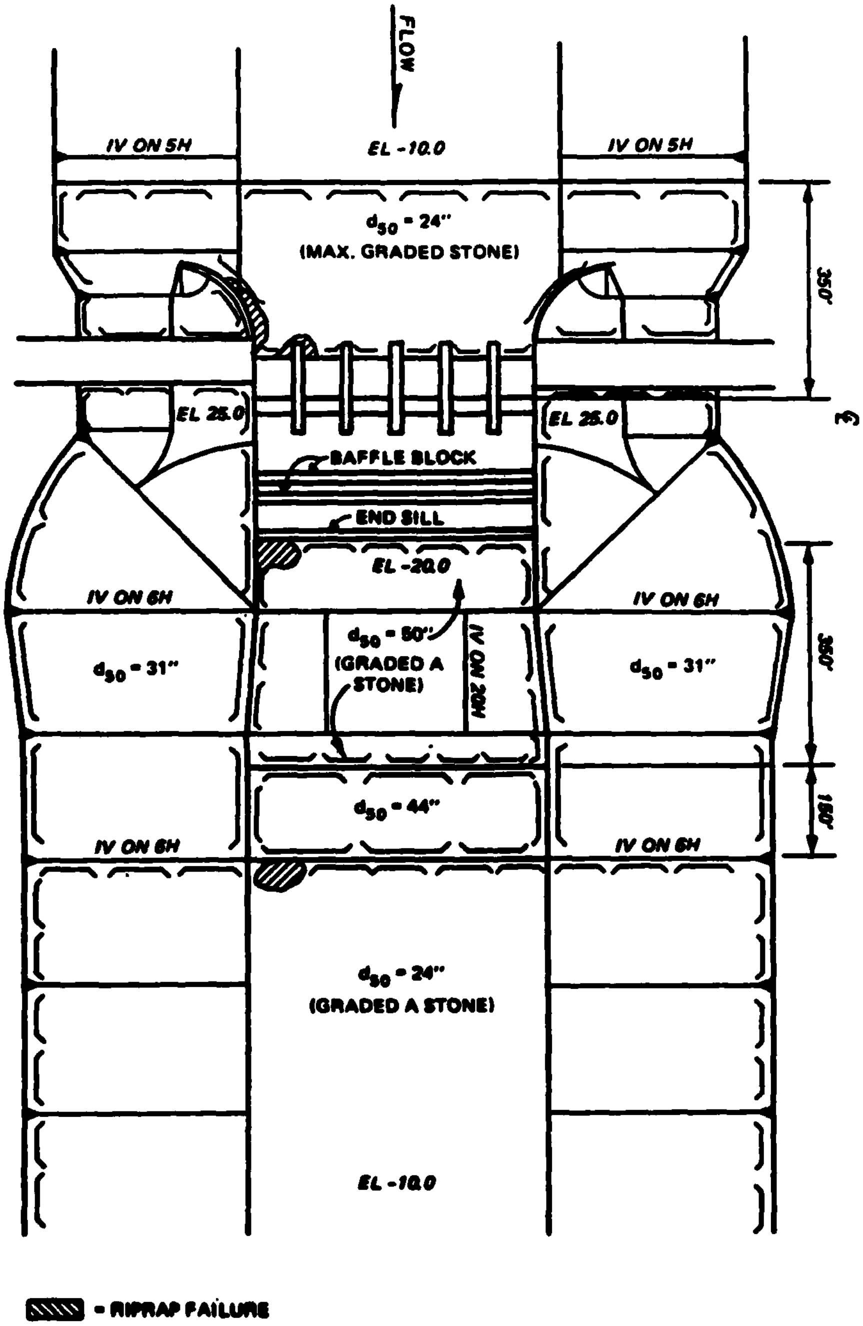
VELOCITY DISTRIBUTION
105 FT DOWNSTREAM FROM END SILL
RECOMMENDED DESIGN
LOOKING DOWNSTREAM
G_o = 36.0 FT



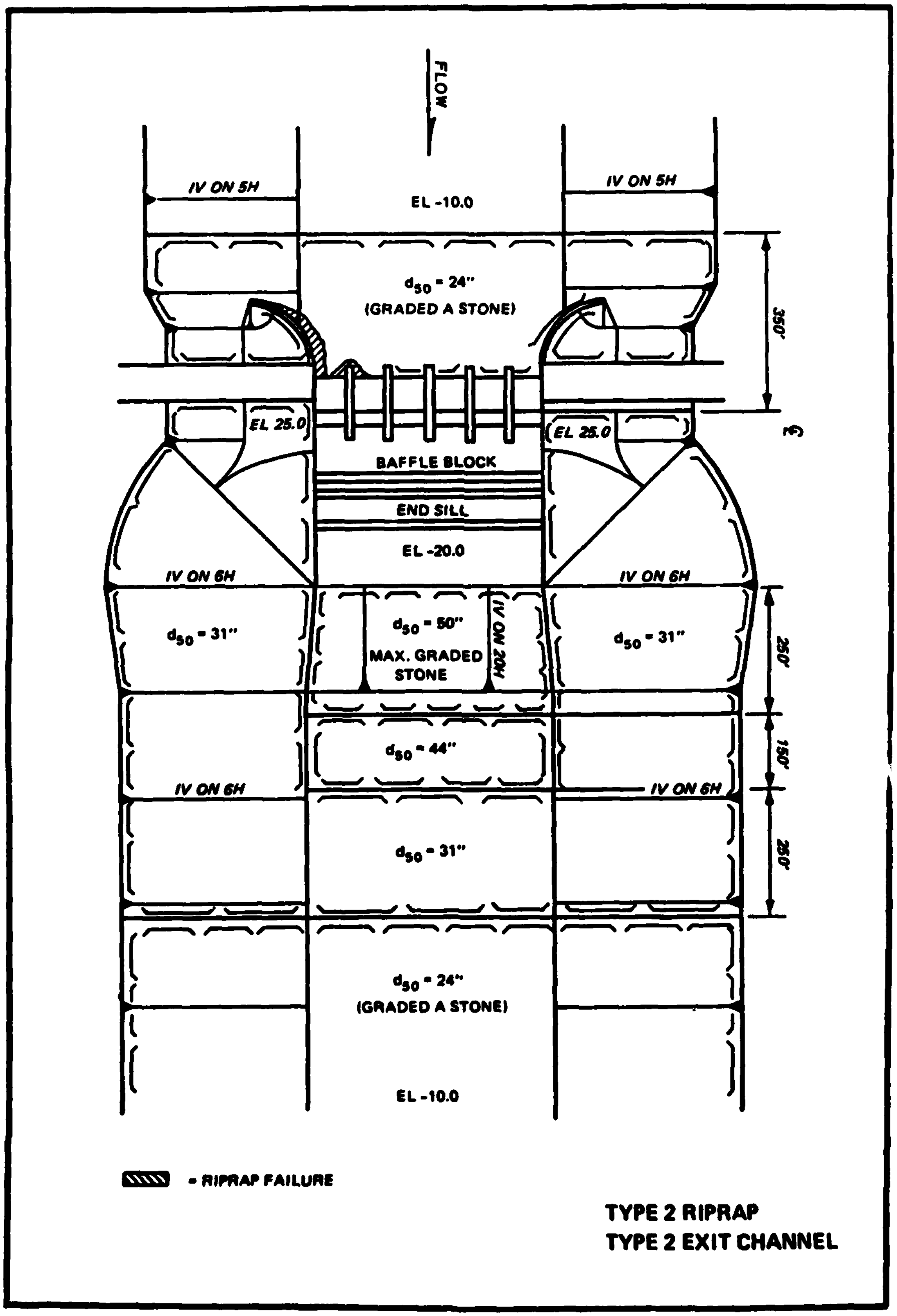
DISCHARGE 374,000 CFS
HEADWATER EL 52.0
TAILWATER EL 38.6

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND

VELOCITY DISTRIBUTION
305 FT DOWNSTREAM FROM END SILL
RECOMMENDED DESIGN
LOOKING DOWNSTREAM
G_0 = 36.0 FT



TYPE 1 RIPRAP
TYPE 2 EXIT CHANNEL


FLOW
IV ON 5H
EL -10.0
IV ON 5H
d_{50} = 24"
(GRADED A STONE)
350'
EL 25.0
EL 25.0
℄
BAFFLE BLOCK
END SILL
EL -20.0
IV ON 6H
IV ON 6H
d_{50} = 31"
d_{50} = 50"
MAX. GRADED
STONE
IV ON 20H
d_{50} = 31"
250'
d_{50} = 44"
150'
IV ON 6H
IV ON 6H
d_{50} = 31"
250'
d_{50} = 24"
(GRADED A STONE)
EL -10.0
= RIPRAP FAILURE
TYPE 2 RIPRAP
TYPE 2 EXIT CHANNEL

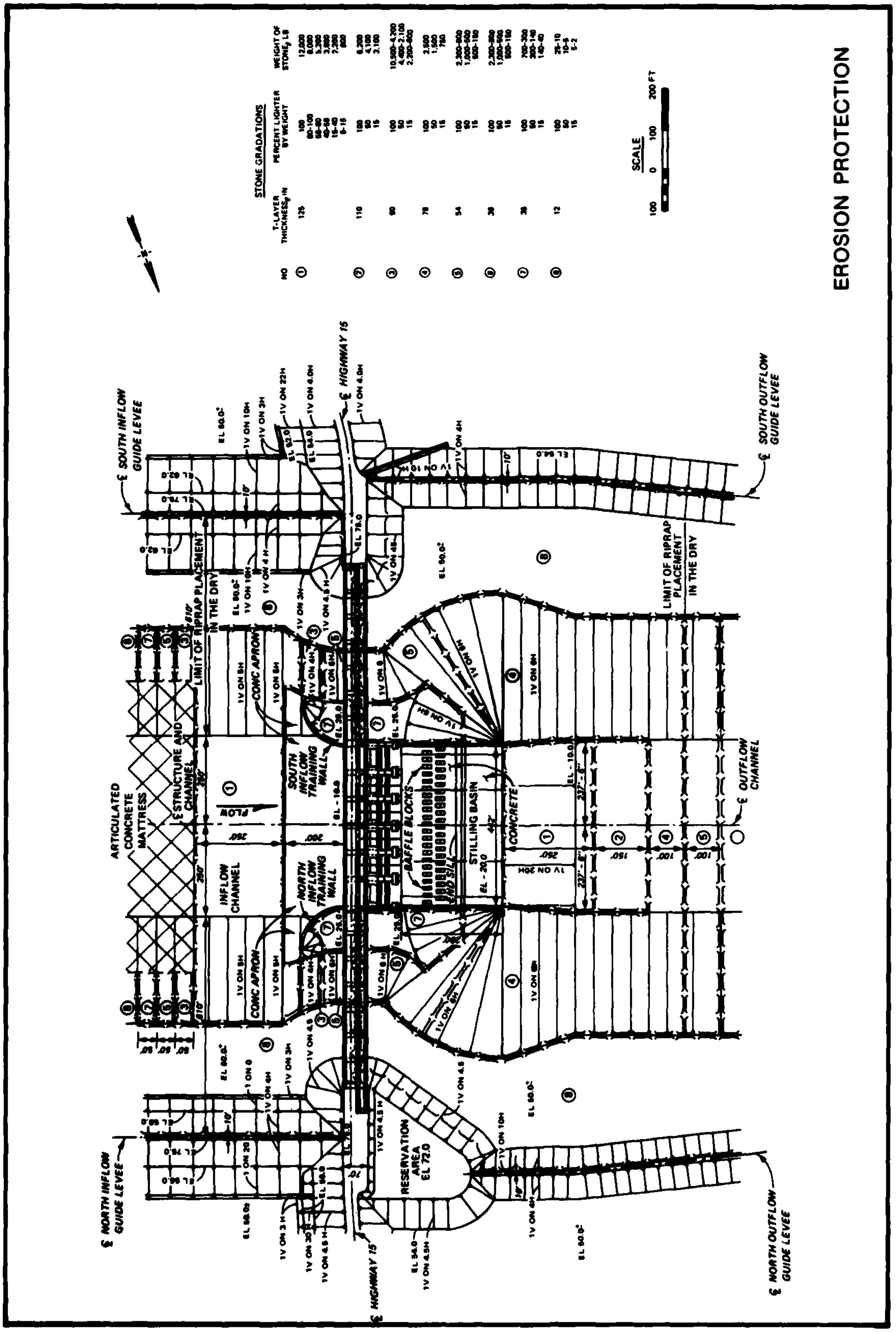
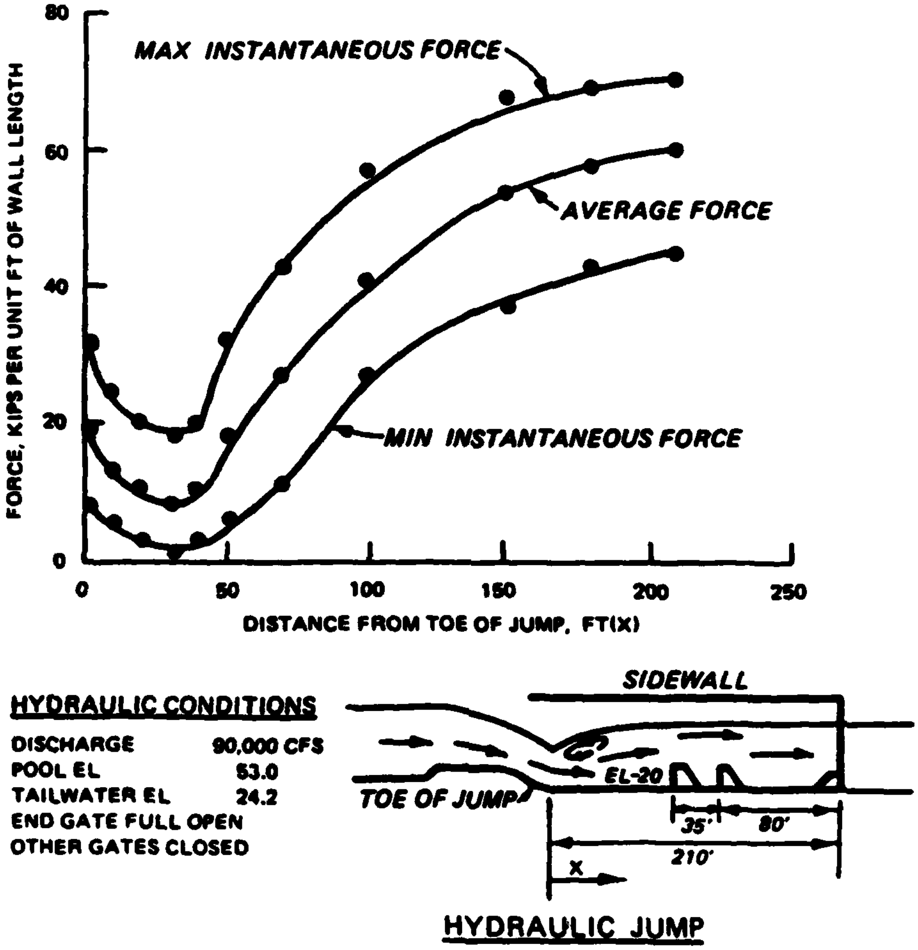
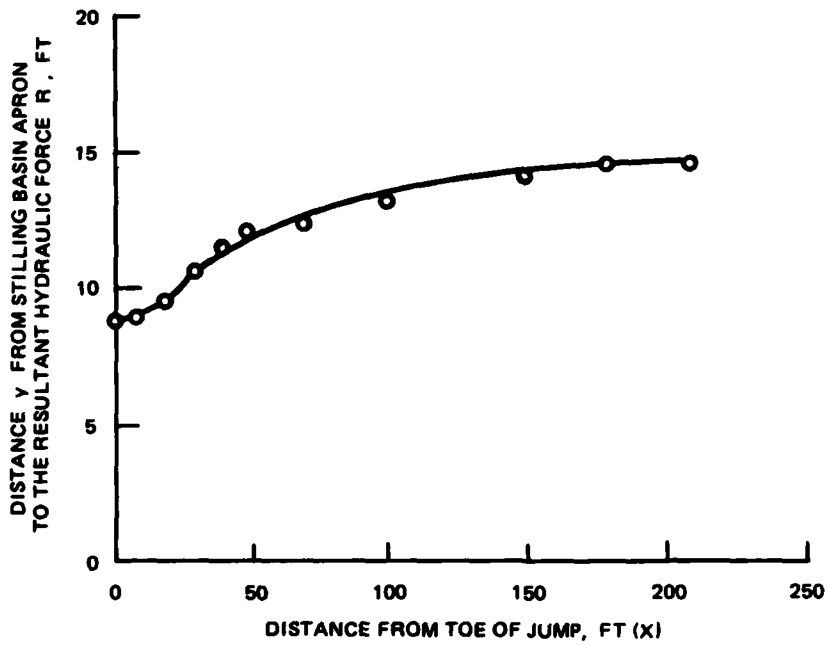

EROSION PROTECTION
STONE GRADATIONS
SCALE
ARTICULATED CONCRETE MATTRESS
INFLOW CHANNEL
NORTH INFLOW TRAINING WALL
SOUTH INFLOW TRAINING WALL
BAFFLE BLOCKS
STILLING BASIN
OUTFLOW CHANNEL
HIGHWAY 15
NORTH INFLOW GUIDE LEVEE
SOUTH INFLOW GUIDE LEVEE
NORTH OUTFLOW GUIDE LEVEE
SOUTH OUTFLOW GUIDE LEVEE
RESERVATION AREA EL 72.0
LIMIT OF RIPRAP PLACEMENT IN THE DRY

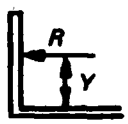
PLATE 67



NOTE. INSTANTANEOUS FORCES OCCUR AT A RANDOM FREQUENCY

FORCE PER FEET OF WALL LENGTH





SIDEWALL

END VIEW

MOMENT ARM PER FEET OF WALL LENGTH